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Technologies and Costs for the Removal of Volatile Organic Chemicals from Potable Water Supplies (Draft)

Environmental Science and Engineering, Inc.
Gainesville, FL

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TECHNOLOGIES AND COSTS FOR THE REMOVAL OF VOLATILE ORGANIC CHEMICALS FROM POTABLE WATER SUPPLIES

For:

SCIENCE AND TECHNOLOGY BRANCH
Criteria and Standards Division
Office of Drinking Water
U.S. Environmental Protection Agency
Washington, D.C.

By:

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Nine volatile organic chemicals are currently being considered for regulation. This report reviews and summarizes the treatment information available on the removal of these compounds from drinking water. Most of the treatment information was obtained through review of laboratory and pilot-scale studies of aeration and activated carbon adsorption processes. Cost estimates for these treatment processes using a variety of raw and treated water concentrations are presented.

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NOTICE

This document is a preliminary draft. It has not been formally released by the United States Environmental Protection Agency (EPA) and should not at this stage be construed to represent Agency policy. It is being circulated for comment on its technical accuracy and policy implications.

1.0 INTRODUCTION

This document is designed to assist with the identification of the best treatment methods or other means that the Administrator of the United States Environmental Protection Agency (EPA) finds to be generally available, taking costs into consideration, pursuant to the Safe Drinking Water Act (SDWA), for use by public water systems in removing volatile synthetic organic chemicals (VOCs) from contaminated water sources. EPA is currently proposing maximum contaminant levels (MCLs) for the VOCs most prevalent in contaminated water supplies, shown in Table 1-1. The treatment and compliance methods available to a community searching for the most economical and effective means to comply with proposed VOC MCLs include modification of existing treatment systems, installation of new systems, and the selection of other water sources.

It is not the intention of EPA to require any system to use a particular treatment method to achieve compliance with proposed VOC MCLs. Instead, the responsibility is retained by the individual water systems to select one or more procedures that are optimal for their particular water supply situation. Whichever individual method or combination of treatment methods is ultimately selected by a water supplier must be based upon a case-by-case technical evaluation of the system's entire treatment process, and an assessment of the economics involved. However, the major factors that must be considered include:

1. Quality and type of water source,
2. Degree of VOC contamination,
3. Specific compound(s) present in water source,

Table 1-1. List of VOCs for Which MCLs Are Being Considered

Trichloroethylene
Tetrachloroethylene
Carbon Tetrachloride
1,2-Dichloroethane
Vinyl Chloride
1,1-Dichloroethylene
Benzene
1,1,1-Trichloroethane
p-Dichlorobenzene

Source: Federal Register, June 12, 1984.

4. Economies of scale and the economic resources available to the community being served,
5. Treatment and waste disposal requirements, and
6. Control of air emissions of VOCs.

The information provided in this document is intended to aid a system in selecting the best treatment method for providing a water free from or with acceptable concentrations of VOCs. It provides the user with an evaluation of the various treatment methods in use today for the removal of different concentrations of VOCs and several nontreatment alternatives, as well as relative costs. The methods that can be applied are divided into three general categories:

Most Effective Treatment Technologies--Technologies that are generally available, have a demonstrated highly effective capacity to remove VOCs, and for which reasonable cost estimates can be developed for a wide range of influent/effluent conditions.

Other Treatment/Alternative Technologies--Nontreatment or compliance measures, such as new sources or regionalization, or technologies which are less efficient or may not be applicable to all plants.

Additional Technologies--Technologies which experimentally have been shown to have potential for removing VOCs, but for which insufficient data exist to fully evaluate the technology.

For waters contaminated with VOCs, the following treatment technologies are designated as the Most Effective Treatment Technologies for all of the system size categories (June 12, 1984, CFR Vol. 49, No. 114):

1. Packed tower aeration, and
2. Granular activated carbon (GAC) adsorption.

Costs estimates developed for the Most Effective Treatment Technologies for the influent/effluent conditions shown in Table 1-2 for each of the 12 system size categories shown Table 1-3 are presented in Section 7.1.

Table 1-2. Influent/Effluent Concentrations for Estimating Costs for Most Effective Treatment Technologies

Chemical	Influent Concentrations (ug/L)*	Effluent Concentrations (ug/L)
Trichloroethylene	500,200,100,50,25,10,5	1,5,10,25,50,100
Tetrachloroethylene	500,200,100,50,25,10,5	1,5,10,15,25,50,100
Carbon tetrachloride	500,200,100,50,25,10,5	1,5,10,25,50,100
1,2-Dichloroethane	500,200,100,50,25,10,5	1,5,10,25,50,100
Vinyl chloride	500,200,100,50,25,10,5	1,5,10,25,50,100
1,1,-Dichloroethylene	500,200,100,50,25,10,5	1,5,10,25,50,100
Benzene	500,200,100,50,25,10,5	1,5,10,25,50,100
1,1,1-Trichloroethane	500,200,100	5,10,200
p-Dichlorobenzene	1,000,500	5,10,750

* ug/L = micrograms per liter.

Table 1-3. Population Ranges and Respective Flow Rates

Category	Population Range	Average Flow Rate
1	25-100	13,000 gpd*
2	101-500	37,000 gpd
3	501-1,000	93,000 gpd
4	1,001-3,300	280,000 gpd
5	3,301-10,000	952,000 gpd
6	10,001-25,000	2.753 MGD†
7	25,001-50,000	6.065 MGD
8	50,001-75,000	11.680 MGD
9	75,001-100,000	15.912 MGD
10	100,001-500,000	36.806 MGD
11	500,001-1,000,000	129.421 MGD
12	>1,000,000	517.491 MGD

* gpd = gallons per day.
† MGD = million gallons per day.

Table 1-2 presents the influent and effluent concentrations used for estimating removal cost. The influent concentrations provide an approximation of the range of concentrations likely to occur in drinking water systems considering treatment. The effluent concentrations are hypothetical MCLs.

The following have been designated as Other Treatment/Alternative Technologies:

1. Multiple-tray aeration,
2. Diffused aeration,
3. Spray aeration,
4. Air-lift pumping,
5. Cascade aeration,
6. Mechanical aeration,
7. Powdered Activated Carbon (PAC) Adsorption,
8. Well field management,
9. Bottled water,
10. Regionalization, and
11. Alternate source.

Cost estimates developed for Other Treatment/Alternative Technologies for the 12 system size categories shown in Table 1-3 are presented in Section 7.2.

Additional Treatment Technologies include the following:

1. Point-of-use and point-of-entry devices, home carbon adsorption units, distillation units;
2. Point-of-use and point-of-entry devices, home reverse osmosis units; and
3. Ozone plus ultraviolet (UV) radiation.

Cost estimates developed for Additional Treatment Technologies are presented in Section 7.3.

2.0 BACKGROUND

The water supply testing programs conducted by federal, state, and local government agencies have identified VOC contamination of water supplies as a widespread occurrence warranting evaluation of potential health effects and requiring regulatory action. On March 4, 1982, EPA published an Advanced Notice of Proposed Rulemaking (ANPRM) in the Federal Register regarding proposed regulation of VOCs in drinking water.

Four workshops on the proposed VOC regulations were subsequently funded by the EPA Office of Drinking Water (ODW) and conducted jointly by EPA and the American Water Works Association Research Foundation (AWWARF) during July through August 1982. The purpose of the workshops was to inform representatives of water utilities, related industries, state regulatory agencies, local officials, environmental and public interest organizations, and other interested parties of the data EPA had gathered and the regulatory approaches it was considering and to generate discussion, comments, and recommendations on the data and possible control measures. The leaders of the workshops were nationally recognized authorities in water treatment, chemistry, toxicology, and process design. The workshops provided both valuable communication between various interested groups and input to the regulatory process.

The overall consensus of the workshops was that contamination by VOCs is a national problem warranting action. Establishment of MCLs and monitoring programs was recommended, provided the health effects data are valid and indicate the need to reduce human exposure to VOCs.

The workshops pointed out potential problems which could arise under various regulatory scenarios. EPA has attempted to address as many of the concerns raised during the workshops as possible in its implementation and promulgation of the VOC regulation.

Aeration (packed tower and diffused) and GAC adsorption were identified as generally available technologies effective in removing 99 percent or more of the VOCs from contaminated water supplies. Preliminary cost estimates presented by EPA were considered to be reasonable.

A review of the current literature reveals that packed tower aeration and GAC adsorption are capable of greater than 99-percent removal of VOCs under a broad range of conditions. The other technologies mentioned in this document do not have such a proven capability under a variety of conditions. Appendix A lists the estimated removal efficiencies for the other treatment technologies. Under some local conditions, these technologies may be able to cost effectively reduce VOC concentrations to the hypothetical MCL, but generally their removal efficiencies are lower than packed tower aeration or GAC adsorption. Some technologies in the other treatment/alternative technologies category are not always available (e.g., alternate source or regionalization). The additional treatment technologies were so grouped because there is limited evidence of their efficacy. Some limited data indicate that home carbon adsorption units remove VOCs, but questions remain about microbiological safety and the feasibility of central management. The data on RO and ozone plus UV are too limited to judge efficacy or to estimate cost.

3.0 EFFECTIVE TECHNOLOGIES FOR REMOVAL OF VOCS FROM DRINKING WATER

Other than some incidental volatile losses (usually less than 10 percent), conventional water treatment consisting of coagulation, sedimentation, precipitative softening, filtration, and chlorination is ineffective for reducing concentrations of VOCs (Robeck and Love, 1983). The two general treatment processes which have been found to be effective for removal of VOCs from drinking water are aeration and adsorption.

3.1 AERATION

Aeration for removal of VOCs from water takes advantage of the natural tendency of VOCs in water to migrate into clean air. The degree to which the contaminant leaves the water phase and enters the air phase is dependent on a combination of physiochemical characteristics of the contaminant [such as Henry's Law constants, diffusivity (the proportionality factor between the molar flux and concentration gradient), and molecular weight] and the design of the aeration system employed. Table 3-1 lists important physiochemical characteristics, some of which can potentially affect VOC removal by aeration. One of the more important characteristics of a volatile chemical regarding its amenability to aeration is its Henry's Law constant. Figure 3-1 shows graphically a comparison of Henry's Law constants for several VOCs. The greater the Henry's Law constant (in the units shown in Figure 3-1) for a particular VOC, the easier a VOC is removed from water by aeration. Because the Henry's Law constant increases with increasing temperature, the water temperature will also affect the amenability of a contaminant to removal by aeration. The Henry's Law constant of a compound is only a preliminary indicator of its ability to be removed by air stripping. Empirical evidence indicates that some compounds are more difficult to remove and some are more easily removed than would be estimated based on the Henry's Law constant alone.

Various forms of aeration are available and include tower aeration, diffused aeration, spray aeration, and air-lift pumping. Figure 3-2 shows schematic diagrams of these system types.

Table 3-1. Comparative Data for Selected VOCs

Parameter	Chloroethylenes				Chloroethanes		Carbon tetra-chloride	Benzene	p-dichloro-benzene
	tri-	tetra-	1,1-di-	vinyl chloride	1,1,1-tri-	1,2-di-			
Molecular weight, g/mole	132	166	97	62	133	99	154	78	147
Density, g/ml	1.46	1.62	1.22	0.92	1.34	1.24	1.59	0.89	1.25
Boiling point, °C atmospheric	86.7	121	32	-14	74.1	83.5	76.7	80	147
azeotropic (w/H_2O)	73.2	88.5	NR	NR	65	71.6	66.8	69.4	NR
Solubility, mg/L	1000 1100	150 140	40	60	4400 5497	8700	800	1780	79
Vapor pressure, mm Hg	74	18.6	495	2660	100	82	91.3	95	1.0
Henry's Law Constant									
$\frac{\text{conc. (air)}}{\text{Conc. (water)}}$	0.48 0.49	1.1 1.2	7.8	50 301	0.17 1.2	0.05	1.2	0.22	0.10
$\times 10^{-3}\frac{\text{atm-m}^3}{\text{mole}}$	11.7	28.7	150	6400	4.92	1.10	30.2	5.55	1.94

Table 3-1. Comparative Data for Selected VOCs (Continued, Page 2 of 2)

	Chloroethylenes				Chloroethanes		Carbon		
Parameter	tri-	tetra-	1,1-di-	vinyl chloride	1,1,1-tri-	1,2-di-	tetra- chloride	Benzene	p-dichloro- benzene
Threshold odor concentration, ug/L	500	300	NR	NR	NR	2000		31,300	NR
Parachor	212.8	250	175.6	211.3	223.9	186.6	222.0	207.1	280.5
Molar refraction	30.42	35.21	20.71	23.85	24.95	21.18	26.30	26.2	36.1

*Calculated from solubility and vapor pressure.

NR = Not reported.

Source: EPA, 1983.

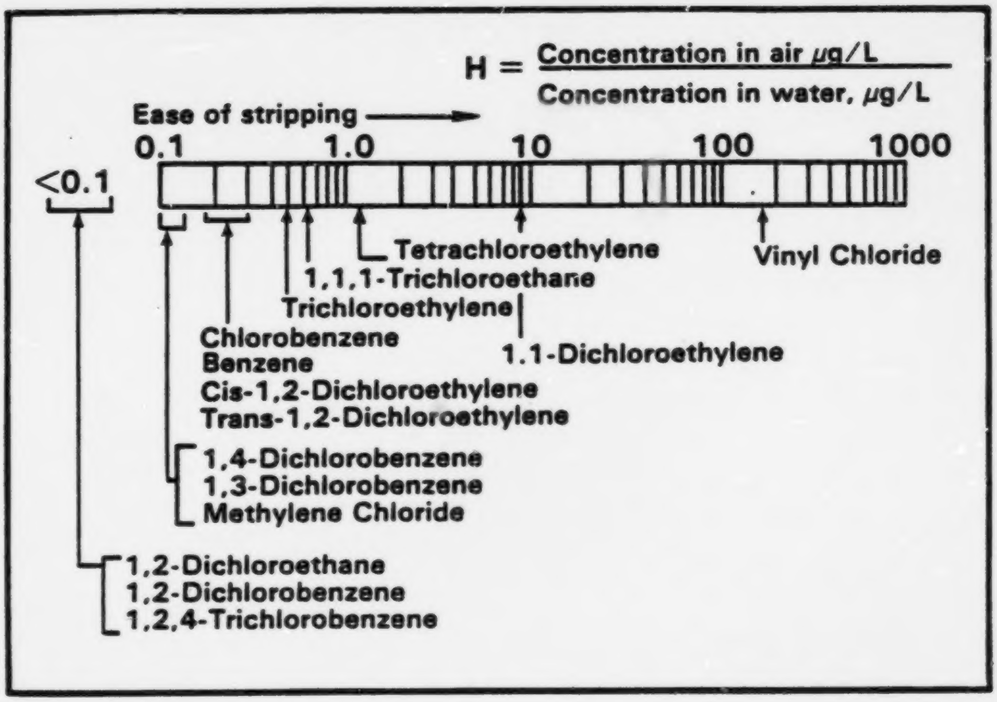

Figure 3-1
COMPARISION OF HENRY'S LAW CONSTANTS FOR SELECTED ORGANICS

SOURCE: ROBECK AND LOVE, 1983.

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OFFICE OF DRINKING WATER

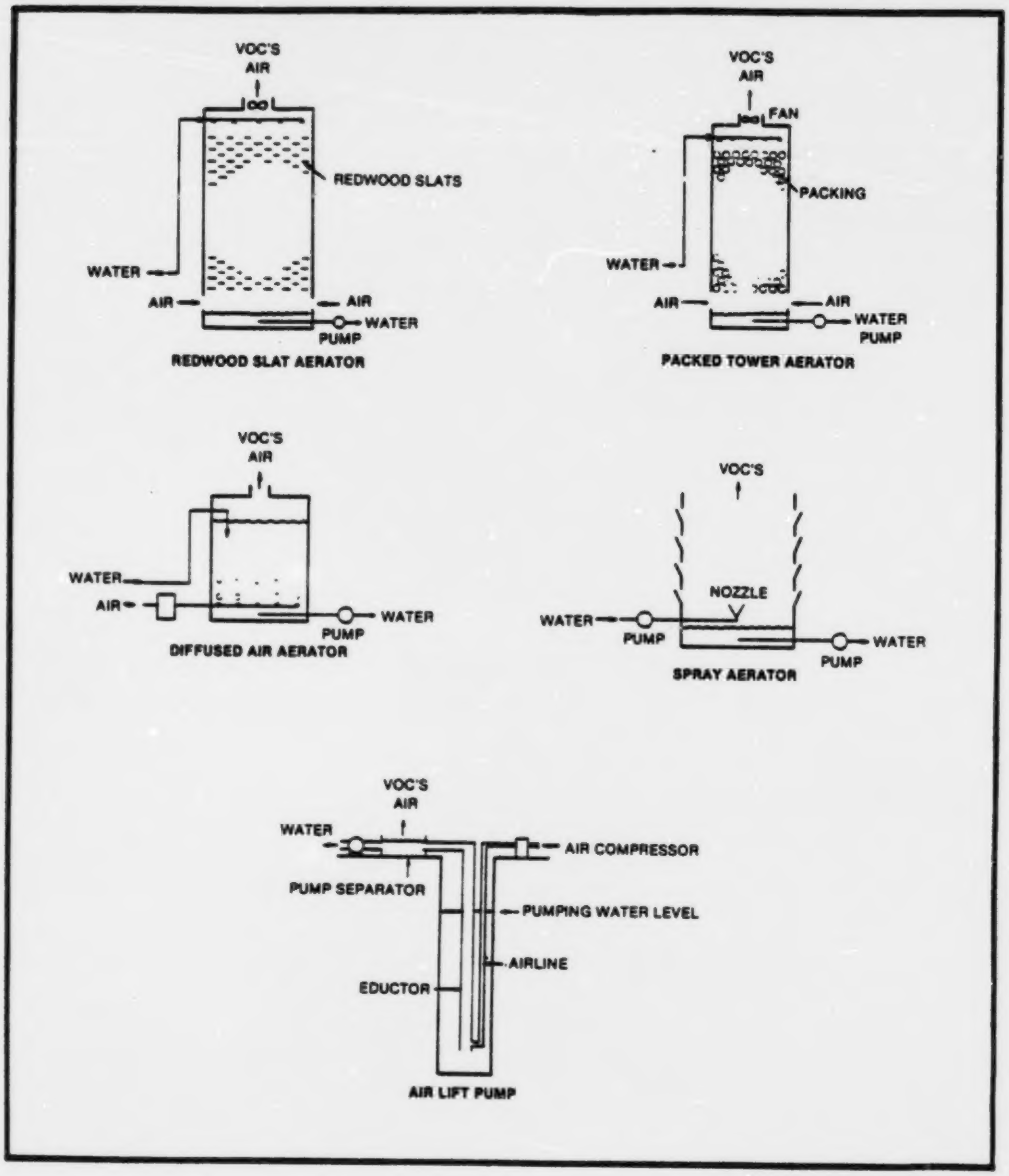
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Figure 3-2
AERATION DEVICES USED TO REMOVE VOLATILE ORGANIC COMPOUNDS FROM DRINKING WATER

SOURCE: ROBECK AND LOVE, 1983.

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF DRINKING WATER

The physical chemistry of the transfer of VOCs from water to air can be simplified for this discussion. A gas dissolved in a liquid can readily move between the gas and the liquid phase. The rate of transfer is governed by the relative concentrations of gas (VOC) in the water versus that in the air. The controlling factor in the removal of VOCs from water is the rate of transfer from water to air until equilibrium is reached. If high volumes of uncontaminated air are brought into contact with VOC-contaminated water, very high levels of removal are achievable (greater than 99 percent). Air contaminated with VOCs will impede the stripping process. This factor should be considered in site-specific pilot-plant testing and design of aeration process.

In tower aeration designs, water is pumped to the top of the unit and allowed to trickle downward through trays or other media, contacting air in the process. The thin film of water formed as the water flows over the media provides a large surface area for mass transfer of the VOCs from water to air. The various types of tower aeration differ in the physical design of the towers and in the methods of introducing air into the tower. Packed towers have a continuous packing media, which can vary in size, shape, and material, while multiple-tray aerators have trays with slats, perforations, or wire mesh bottoms over which the water falls and eventually collects in the bottom. Cascade aerators have steps or baffles over which the water falls. Packed towers are usually equipped with blowers to increase the air flow rate through the tower. Multiple-tray aerators are usually equipped with blowers, but are sometimes open sided and depend on natural ventilation. Air can be supplied to tower aerators by forced air or induced air blowers.

Diffused aeration involves bubbling air through water in a chamber through a diffuser or set of diffusers, usually mounted at or near the bottom of the chamber. The removal efficiency of diffused aeration is dependent on several factors, including diffuser type, bubble size, air-to-water ratio, water depth, detention time, and water temperature (Albin and Holdren, 1982).

Spray aeration involves spraying the contaminated water into the air through a set of nozzles. The small droplets which form provide a relatively large surface area through which the volatile chemicals may migrate into the air. Factors which affect the removal efficiency of spray aeration systems have not been studied thoroughly. These factors are likely to include the size of the water droplets formed (surface area for mass transfer), height of spray (contact time), and temperature.

In addition to the removal of VOCs, the use of aeration technologies may also result in additional secondary effects, some of which may be undesirable. These secondary effects may include:

1. Removal of hydrogen sulfide and carbon dioxide, and the oxidation of iron and manganese;
2. Introduction of dissolved oxygen into the water;
3. Introduction of bacteria or airborne contaminants into the water;
4. Potential air quality problems created by contaminated exhaust gases from the aeration system; and
5. The pH of the raw water may increase upon aeration. In some cases this is beneficial, but sometimes it results in an increase in carbonate stability such that scaling occurs in the distribution system.

EPA (Love *et al*., 1984) is currently studying the secondary effects of aeration. These include introduction of bacteria and particulates, increased corrosivity, cold weather problems, oxidation of iron, bacterial growth on the packing materials, and introduction of VOCs into the air. The preliminary findings of these studies are as follows. The results from an ongoing EPA study at Glen Cove, New York, indicate no detrimental effects on water quality due to increased particulates, turbidity, or bacteria following aeration. Bacterial clogging occurred in one instance, but appeared to be related to a specific clear plastic packing material. When water contains carbon dioxide, aeration tends to increase pH, which can be a beneficial effect for soft waters. The addition of excess dissolved oxygen, which can increase corrosivity of iron pipe material, usually can be controlled by allowing degasification. Corrosion control and carbonate stability should be a design consideraton in all aeration processes. Proper design can also avoid cold weather problems, according to Love et al. (1984). Excessive iron and manganese can cause clogging, so it is usually advisable to remove these compounds prior to aeration processes for VOC removal. All EPA investigations conducted to date indicate that increased levels of VOCs in air would contribute little to human population risk. In summary, the secondary effects of aeration have been considered and are thought to be manageable.

Of the various types of aeration available, packed tower aeration has been the most thoroughly studied. The theory and design of packed tower aeration systems has been well developed in the engineering literature (Treybal, 1980; Perry and Chilton, 1973; Cummins, 1983; Kavanaugh and Trussel, 1980).

Given an influent and desired effluent concentration, water temperature, packing material characteristics, approximate Henry's Law constant, and molecular structure of the particular VOC along with a set of assumptions concerning economic factors (unit costs for system components, electricity, etc.), a reasonable estimate of the cost of a particular packed tower system can be developed. Packed tower aeration also provides the greatest efficiency of VOC removal under a variety of conditions. For this reason, packed tower aeration has been designated to be a Most Effective Treatment Technology. The remaining forms of aeration (slat-tray, diffused, spray, and air-lift pumping) have been designated as Other Treatment/Alternative Technologies because either (1) they generally have lower removal efficiencies than packed tower aeration or GAC adsorption or (2) sufficient data were not available to estimate with reasonable accuracy the cost of various systems for removing VOCs of concern from a given influent concentration to a desired effluent concentration (e.g., spray aeration, air-lift pumping).

3.2 ADSORPTION

Both GAC and PAC have been used for adsorption of an extremely diverse number of organic compounds from various aqueous solutions. In addition, a synthetic resin, Ambersorb® XE-340, has been shown to be an effective adsorbent for several VOCs (Ruggiero *et al*., 1980). The manufacturer of this resin is not expected to produce it commercially (Love and Miltner, 1982), and synthetic resin adsorption was not considered further. Application of resin adsorption is currently limited by the high cost of producing the resins. Most of the significant variables which affect the performance of a particular adsorption system have been studied and are reasonably quantifiable (Weber, 1972; Suffet and McGuire, 1980). GAC has been found to be more effective than PAC in removing VOCs from drinking water (Love and Eilers, 1982).

PAC will have limited application for many ground waters, since most systems do not have the basins and filters necessary for this technology. GAC is applied in a column where VOCs adsorb until the influent concentration is in equilibrium with the carbon surface. Since PAC moves along with the flow of water being treated, the carbon surface approaches equilibrium with the effluent concentration. Because the adsorption isotherms of the VOCs are steep, more compound is adsorbed per gram of carbon in a column. Thus, GAC is a much more likely application versus PAC.

Adsorption of organic compounds by activated carbon involves a complex interaction of specific characteristics of the organic compounds being adsorbed (i.e., molecular structure, molecular weight, molecular size, stereochemistry, solubility, polarity, and concentration) and specific characteristics of the carbon adsorbent (i.e., surface area, micropore/macropore structure, and types and number of functional groups present on the carbon surface) (Suffet and McGuire, 1980). Additional factors such as pH, ionization state, presence of other organic compounds in the water, and temperature can affect the adsorption of many compounds (Weber, 1972).

Although the adsorption characteristics of the individual VOCs vary, numerous studies have shown that VOCs as a class of compounds are generally amenable to activated carbon adsorption (EPA, Water Supply Research Division, 1978; Wood et al., 1980; Weber and Pirbazari, 1981; Troxler et al., 1980; Yohe and Suffet, 1979). Figure 3-3 shows adsorption isotherms for 13 VOCs, as determined in batch equilibrium studies using pulverized GAC and distilled water (Dobbs and Cohen, 1980; Weber and Pirbazari, 1981). This figure is useful in comparing the general amenability for adsorption among the VOCs, although the particular adsorptive capacity of a particular carbon for a VOC may vary under different conditions. For example, actual capacities of GAC for several VOCs reported in pilot-scale field studies were two to three times higher than those predicted by the Dobbs and Cohen isotherm data shown in Figure 3-3 (Love and Miltner, 1982). The difference in capacity may have been due to in situ biodegradation of organics adsorbed on the carbon in the field studies (Love and Eilers, 1982) or to the use of only a 2-hour contact time in the isotherm study (AWWARF, 1983). The result could have also been due to matrix effects, kinetic effects, competition, or unknown reasons. [Additional isotherm studies with longer contact time are currently being conducted by EPA (Love and Miltner, 1982).]

The dynamic minicolumn method of determining carbon usage rates also appears to be of use in developing design criteria (Bilello and Beaudet, 1983). Data from this system can be used to determine if carbon treatment for a given water is feasible and to provide a rough estimate of costs. The scale-up factors for design of full-scale systems still remain to be developed, however. Once the scale-up factors are developed, the dynamic minicolumn data could be quite useful.

Several water quality parameters of the raw water source to be treated may affect the design of the activated carbon adsorption system used. Surface waters may contain turbidity, algae, diatoms, or other materials which could adversely affect the adsorption process, if not removed by pretreatment. Surface water generally has contaminants and competing

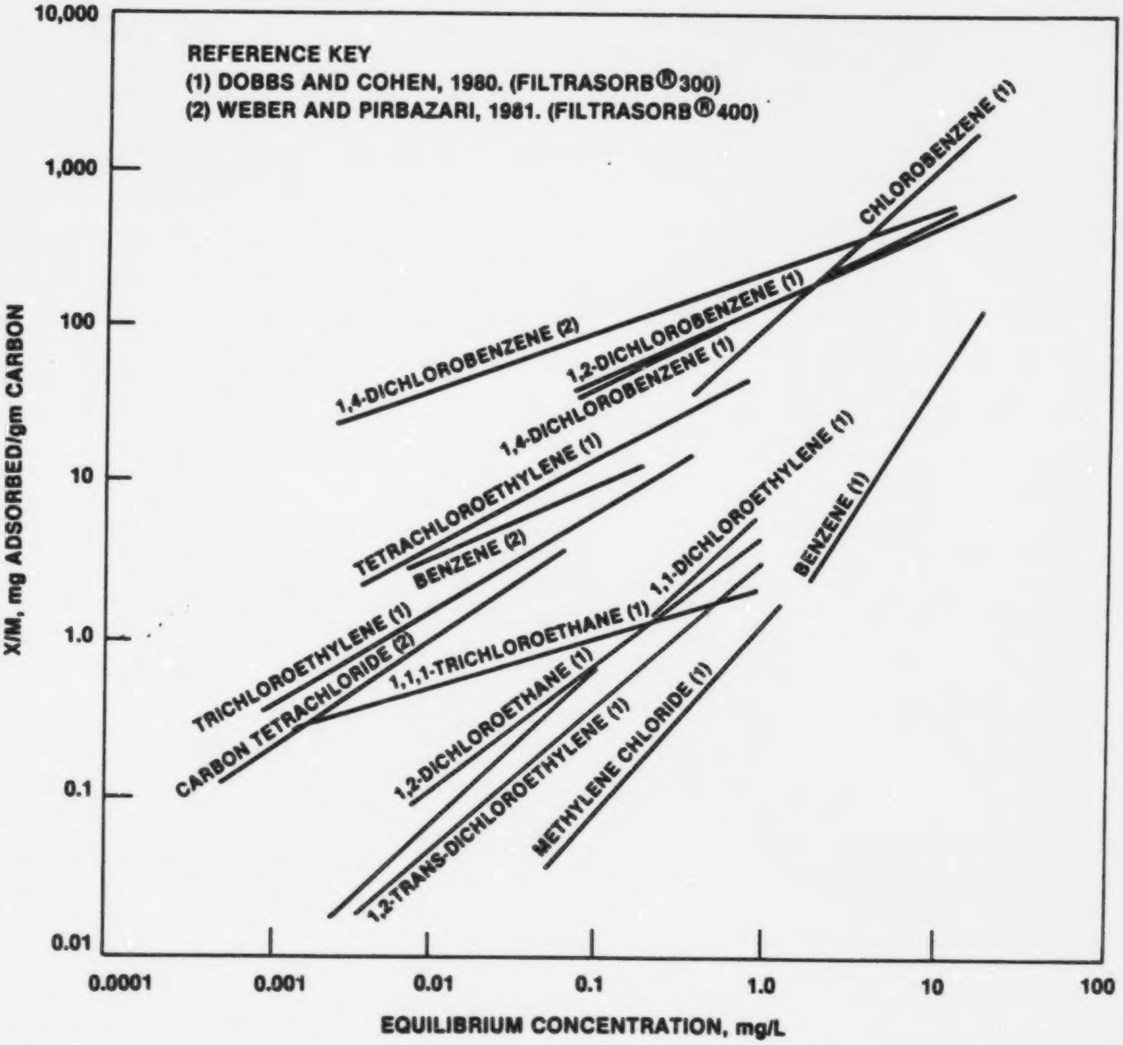

Figure 3-3
COMPARISON OF ADSORPTION
ISOTHERMS FOR VOCs

SOURCES: DOBBS AND COHEN, 1980;
WEBER AND PIRBAZARI, 1981.

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organics that vary widely in concentration both daily and seasonally (AWWARF, 1983). The species and concentration of contaminant that must be removed from ground water does not vary as widely over short time spans. However, ground water is more likely to contain reduced materials, such as iron or manganese, which can oxidize and precipitate on the carbon where they may reduce the effectiveness of GAC treatment, if not removed.

Competitive adsorption and the influence of high concentrations of background organic carbon on the removal of VOCs by activated carbon are recognized, but not well understood (Robeck and Love, 1983). The degree of competition expected from natural organics is difficult to predict because of the wide variation in their adsorbability (McCreary and Snoeyink, 1980). Robeck and Love (1983) noted that a high total organic carbon (TOC) content (e.g., 1.5 to 2.0 mg/L) can result in lower-than-anticipated adsorption capacities.

The selection of a particular carbon for a system will depend on several factors, including its performance characteristics in removing the particular contaminant (from isotherm or pilot-scale studies), as well as the conditions of its anticipated use. For example, low density carbons are usually quite friable and subject to attrition during transport and filter backwashing (AWWARF, 1983). If thermal reactivation is to be used, higher losses are expected for low density, friable carbons. However, if the system size is small and the carbon is used on a "throw-away" basis (that is, no reactivation of the carbon), low density carbons may be more feasible.

An important secondary effect of activated carbon, which should be considered by water suppliers contemplating the use of activated carbon, is its reaction with and reduction of chlorine. Both free chlorine and combined chlorine (chloramines) are effectively reduced by activated carbon. The mechanism of reduction and the subsequent oxidation of the carbon surface with free chlorine (Magee, 1956) and with chloramines (Bauer and Snoeyink, 1973) have been described.

GAC processes have been found to provide fertile breeding grounds for colonies of bacteria. Eberhardt (1976) reported on the mineralization of organic substances during treatment of surface water by using a biologically activated carbon filter. The process consisted of adsorption and concentration of organics on the carbon surface and subsequent microbiological degradation of the adsorbed organics from the activated carbon surface. Bacterial respiration may, in some cases, noticeably increase the dissolved carbon dioxide content of the treated water.

The dynamic behavior of bacterial populations on GAC has been the subject of several studies in recent years (Klotz et al., 1976; Cairo et al., 1979; McElhaney and McKeon, 1978; Parsons et al., 1980). While the results of these studies have not presented a consistent picture of the dynamics of bacterial growth on GAC and in effluent from GAC contactors, all found the average number of bacteria in the effluent from GAC systems to be significantly higher than influent levels.

An 18-month-long study of the effect of a plant-scale GAC system on the microbiological characteristics of a potable water supply found that although GAC treatment did increase the standard plate count (SPC) and membrane standard plate count (m-SPC) organisms, conventional post-chlorination following GAC treatment appeared to mitigate any impact on the distributed water quality (Haas et al., 1983). The bacterial growths associated with GAC have been non-pathogenic organisms and are not generally considered to be a problem under properly controlled circumstances.

No incidents of waterborne disease outbreaks have been linked to GAC systems; however, these studies indicate a need to ensure adequate disinfection of GAC contactor effluents prior to distribution of the water and a need for careful monitoring of the disinfected water.

GAC has been designated as one of the Most Effective Treatment Technologies based on its demonstrated capacity to remove relatively high concentrations of VOCs to less than detectable levels and because its costs are reasonably quantifiable. PAC has been designated as one of the Other Treatment/Alternative Technologies due to its limited effectiveness in removing VOCs. PAC also requires mixing, sedimentation, and filtration facilities which are not usually provided in ground water systems. The exception is when softening or chemical precipitation of iron and/or manganese is practiced.

4.0 MOST EFFECTIVE TREATMENT TECHNOLOGIES

A brief process description, in addition to pilot- and full-scale case studies, for the Most Effective Treatment Technologies is presented in the following sections.

4.1 PACKED TOWER AERATION

Process Description

In packed tower aeration, mass transfer of VOCs from the water to the air is facilitated by mixing of contaminated water and uncontaminated air in a countercurrent flow pattern. Contaminated water is pumped to the top of the column, distributed, and trickled down through a bed of packing material. Uncontaminated air is blown in or drawn into the bottom of the column. The packing material provides a large surface area for mixing of air and water, contact time for the VOC molecules to transfer from water to air, and a large void volume to reduce the energy loss of the air system. Air containing the VOCs is then released to the atmosphere at the top of the column. The concentrations of VOC in air are generally 1 to 5 ppm (volume/volume) due to the large volume of air being discharged.

Case Studies

Wurtsmith, Michigan--The United States Air Force installed a full-scale packed tower aeration system in May 1982 at Wurtsmith Air Force Base, Michigan. The purpose of the tower was to remove trichloroethylene from a contaminated aquifer. The aeration system consisted of two 5-foot-diameter steel towers; each contained 18.5 feet of five-eighths-inch Flex ring packing. Each tower was sized to handle up to 600 gpm of contaminated water, at a maximum surface loading rate of 31 gpm/ft^2. Influent trichloroethylene levels generally ranged from 1,500 to 2,000 ug/L. Preliminary tests showed that at an air-to-water ratio of 25:1, each tower achieved approximately 97- to 99-percent removal of trichloroethylene. When the towers were operated in series, trichloroethylene removals of up to 99.97 percent were achieved (United States Air Force Engineering and Services Center, 1982).

Air was supplied to each tower by a fan-type blower capable of delivering 2,000 cubic feet per minute (cfm). Total pressure drop through the tower was 9 to 10 inches of water (approximately 0.5 inch/foot of packing). The installed cost of the system was approximately $170,000 (1982 dollars).

Tacoma, Washington--A packed tower aeration system was installed in Tacoma, Washington, for the treatment of a potable water supply. In September 1981, one of the largest Tacoma production wells was found to be contaminated with 1,2-trans-dichloroethylene, trichloroethylene, tetrachloroethylene, and 1,1,2,2-tetrachloroethane in concentrations of 30 to 100, 54 to 130, 1.6 to 5.4, and 17 to 300 ug/L, respectively (Nadeau *et al.*, 1983). A packed tower aeration system was selected as the best method for treating the water. Full-scale packed towers were designed from data produced in pilot-plant testing.

The final design consisted of five towers, each 12 feet in diameter, and contained 21 feet of 1-inch plastic saddle packing. The system was designed to treat a maximum flow of 3,500 gallons per minute (gpm).

The height of each tower, with discharge stack, was approximately 50 feet. Each tower was equipped with a 60-horsepower (hp) blower capable of delivering 29,000 cfm through each tower at an approximate air-to-water ratio of 300:1. The system was designed with this relatively high air-to-water ratio to ensure removal of the high concentration of 1,1,2,2-tetrachloroethane, the most difficult contaminant to remove. Using a fast-track schedule, the investigation, design, and construction of the system was completed in less than 4 months. The estimated installed cost of this system was $850,000 (1983 dollars).

Warrington, Pennsylvania--Discovery of trichloroethylene in one of the potable water supply wells in Warrington, Pennsylvania, led to initiation of a program to develop treatment measures to remove the compound below the state-recommended concentration of 4.5 ug/L. Because of the successful utilization of aeration techniques by other municipalities with similar contamination, a packed tower aeration system was chosen as the best treatment method. A 3-foot-diameter, 25-foot-high column was erected and filled with 18 feet of packing consisting of 1-inch Super Intalox® saddles. A 5-hp blower with a capacity of 1,200 cfm was installed to provide air to the base of the unit.

At a flow rate of approximately 200 to 225 gpm, an influent trichloroethylene concentration of approximately 130 ug/L, and an air-to-water ratio of nearly 40:1, the tower produced an effluent with a trichloroethylene concentration of 3.5 ug/L, or approximately 97-percent removal. The cost of the capital equipment installation was approximately $32,000 (not including the engineering design) (1982 dollars).

Superior Tube Company--The Superior Tube Company, Norristown, Pennsylvania, operated three packed tower aeration systems as part of an aquifer decontamination program. Operating characteristics for the three towers are summarized in Table 4-1. The towers achieved greater than 99-percent trichloroethylene removal efficiencies due to the high air-to-water ratios and the use of 1/2-inch ceramic saddles in Systems 1 and 2. The 1/2-inch packing provided a larger surface area for mass transfer than 1-inch saddles. The systems were operated year round. No problems with freezing occurred as long as the flow of water was continuous. Removal efficiency of the units was not affected by seasonal changes in ambient air temperature (Superior Tube Company, 1982).

Rockaway Township--Rockaway Township installed two GAC pressure contactors in late 1980 for removal of trichloroethylene, diisopropyl ether, and methyl tertiary butyl ether (MTBE) from a contaminated ground

Table 4-1. Operating Characteristics for Superior Tube Company Aeration Systems

Parameter	System 1	2	3
Year Installed	1974	1979	1980
Height (feet)	5	20	11
Diameter (inches)	36	20	17
Packing Type	1/2-in ceramic saddles	1/2-in ceramic saddles	1-in ceramic saddles
Hydraulic Flow (gpm)	25	15	29
Hydraulic Loading (gpm/ft^2)	3.5	6.9	18.4
Air Flow (cfm)	240	350	330
Blower Motor (hp)	0.5	1.5	1.0
Air-to-Water Ratio (ft^3:ft^3)	72:1	175:1	85:1
TCE Influent Concentration (ug/L)	13,000-14,000	10,000-13,000	3,000-4,000
TCE Effluent Concentration (ug/L)	30-40	0.1-1.0	50-100
Removal Efficiency (percent)	Approximately 99.7	>99.99	Approximately 97.9

Source: Superior Tube Company, 1982.

water supply. Although providing successful treatment, eventually it became necessary to replace the carbon approximately every 45 days at a cost of $30,000 to $35,000 per replacement (1981 dollars) due to breakthrough of the ethers.

Preliminary aeration pilot-scale testing demonstrated that aeration removed 96 to 99 percent of the ether and virtually all of the trichloroethylene. A full-scale unit was designed and placed into operation on February 4, 1982 (McKinnon and Dyksen, 1984).

Initial aeration results showed that the concentration of MTBE was reduced from 37.5 to 1.2 ug/L (96.8 percent) and of diisopropyl ether from 47.0 to 0.3 ug/L (99.4 percent).

The aeration tower was a 35-foot-tall, 9-foot diameter aluminum cylinder. The tower was filled with 25 feet of polypropylene packing. The tower was equipped with two 27,000-cfm belt-driven blowers each powered by a 100-hp motor. At design flow of 1,400 gpm, the air-to-water ratio is approximately 200:1. A mist eliminator was installed to prevent this high volume of air from carrying water out of the top of the tower. The installation included an extra blower for continuous operation.

Effluent from the tower drained into a collection chamber. An electrode probe in this chamber turned on two booster pumps when the chamber was full. The two pumps moved the aerated water through the activated carbon adsorbers, after which it was chlorinated and pumped to the distribution system. Unit controls were protected against power failure and freezes.

United States Environmental Protection Agency--A pilot packed tower aerator has been designed, built, and operated by the Technical Support Division of EPA's Office of Drinking Water. The tower was 2 feet in diameter and contained 18 feet of 1-inch plastic saddles. The system has been operated on contaminated ground water at 18 different sites. Mass transfer coefficients and Henry's Law constants were developed from analyses of the VOC concentration profile at multiple sampling points in the column packing. Analysis of the data revealed that the correlations developed by Onda et al. (Perry and Chilton, 1973) accurately predict the performance of packed tower stripping of most VOCs, with the notable exception of vinyl chloride. Utilization of a field-determined Henry's Law constants usually resulted in better fit of field and predicted data than use of literature values, many of which are estimates from questionable vapor pressure and solubility data.

The performance of the pilot system in removal of eight of the nine VOCs being considered for regulation is shown in Table 4-2. The data were averaged by air-to-water ratio for convenience. Other factors, such as temperature, air loading, and liquid loading, affect the removal.

Table 4-2. VOC Removal by EPA Pilot Packed Column*

Compound	No. of Sites	Temperature (°C)	Average Percent Removal at Air-to-Water Volume Ratios Shown					
			80	45	25	15	8	5
Trichloroethylene	8	10-16	99.7	99.3	97.2	91.4	75	55
Trichloroethylene	1	26	>99.99	>99.99	99.3	99.7	91.0	86
Tetrachloroethylene	4	11-16	99.8	99.5	98.3	96.1	86	72
1,2-Dichloroethane††	1	16	†	98.5	93.0	87	77	85
1,1-Dichloroethylene	2	12-14	99.99	99.7	99.3	98.8	95.4	90.6
Benzene	1	20	99.98	99.8	98.6	94.8	82	†
1,1,1-Trichloroethylene	4	11-14	99.92	99.4	98.2	95.7	86	77
p-Dichlorobenzene††	1	26	(99.9)**	90.8	98.5	85	†	57
			20	5	2	1	0.5	0.2
Vinyl Chloride	1	27	99.99	99.54	98.6	95.7	88	62
			160	88	50	27		
Vinyl Chloride	1	9	99.27	98.7	98.5	97.3		

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*Data from field evaluations of a column containing 18 feet of 1-inch plastic saddle packing operated at contaminated ground water sites.

†No data.

**A:W = 100:1.

††Low influent concentrations make these data less reliable than those for the other compounds.

4.2 GRANULAR ACTIVATED CARBON (GAC) ADSORPTION

Process Description

Granular activated carbon is applied in a stationary column, or filter bed. The organic chemical contaminants are adsorbed until the influent concentration is in equilibrium with the carbon surface. Two types of adsorber units are available. The first is a pressure contact unit shown in Figure 4-1. The second type of adsorber unit is a gravity flow adsorber similar to a rapid sand filter.

Granular activated carbon is placed in the adsorber unit and water is passed through the contactor where contaminants are adsorbed onto the carbon surface. Additional head space is provided above the carbon bed to allow for periodic backwashing.

Granular activated carbon adsorbers are equipped with pumps, valves, and piping to facilitate raw water application, backwashing, and carbon removal and replacement. Exhausted carbon is removed from the adsorber unit and replaced. The exhausted carbon can be disposed of, or reactivated onsite or offsite.

Case Studies

The results of several pilot-scale studies using GAC for removing various VOCs from water supplies are described in the following sections to illustrate the type of information which can be obtained in pilot studies.

New Hampshire and Connecticut--In the summer and fall of 1977, EPA-Drinking Water Research Division (DWRD) installed pilot-scale adsorption columns (1.5-inch diameter with 31 inches of GAC) near contaminated wells at two water utilities in New England, one in Connecticut and the other in New Hampshire. The empty-bed contact time (EBCT) of the carbon column in the New Hampshire study was 9 minutes; EBCT in the Connecticut study was 8.5 minutes.

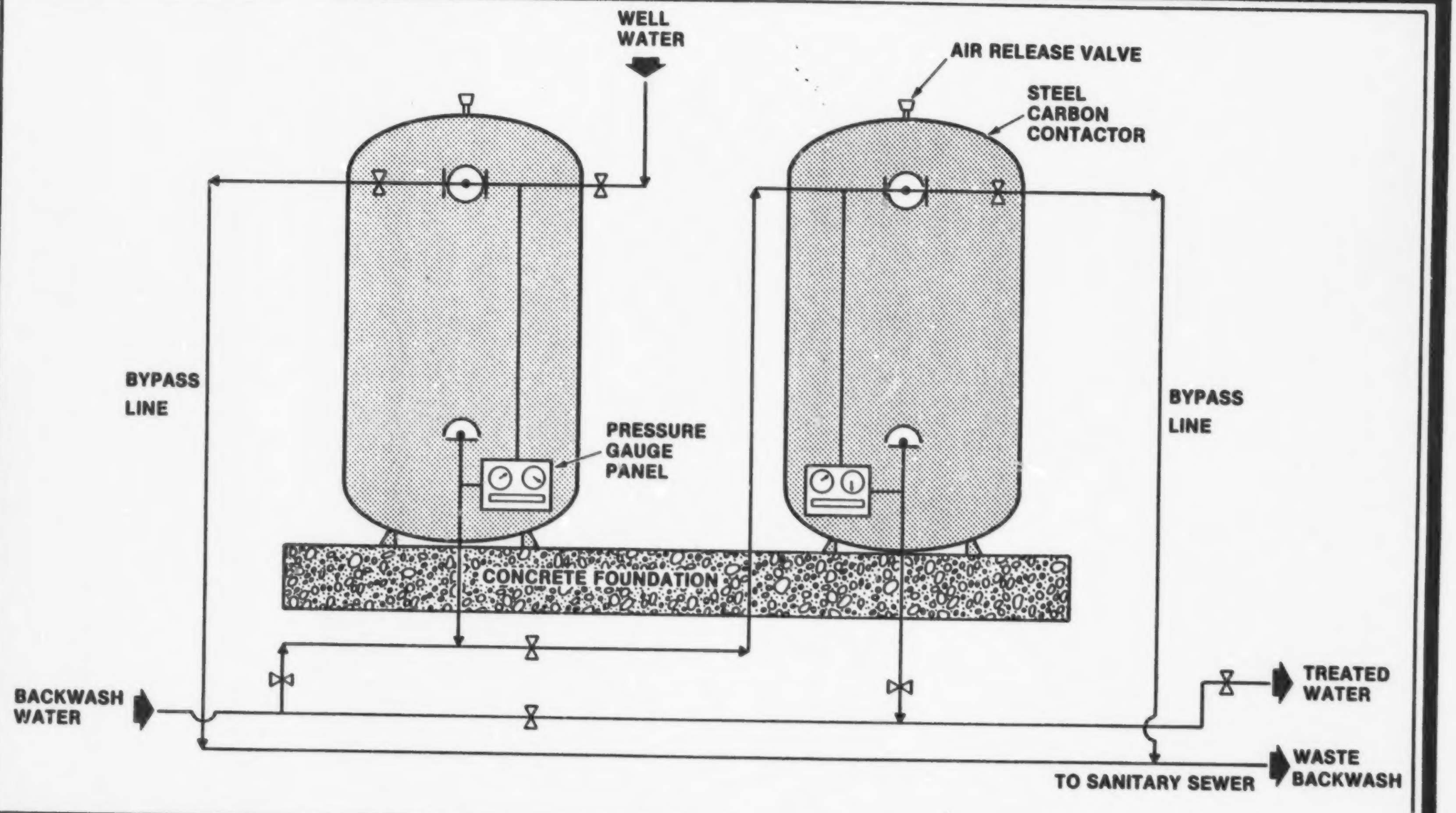
WELL WATER
AIR RELEASE VALVE
STEEL CARBON CONTACTOR
BYPASS LINE
PRESSURE GAUGE PANEL
BYPASS LINE
CONCRETE FOUNDATION
BACKWASH WATER
TREATED WATER
WASTE BACKWASH
TO SANITARY SEWER

Figure 4- 1

SCHEMATIC DIAGRAM OF GAC TREATMENT SYSTEM, NORTH PENN WATER AUTHORITY

SOURCE: ESE, 1982.

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In the New Hampshire study, trichloroethylene concentrations ranged from 120 to 276 ug/L. In addition to trichloroethylene, cis-1,2-dichloroethylene was present in concentrations ranging from 2 to 10 ug/L.

GAC (Filtrasorb® 400) performance for removing these two compounds at the New Hampshire pilot-plant study is shown in Figure 4-2. After 18 weeks, the test column became clogged with what appeared to be precipitated iron. When cleaning was attempted, the contaminant wave front was disrupted, and the study was ended after 23 weeks. In Figure 4-2, it can be seen that cis-1,2-dichloroethylene broke through the column before this disruption and actually exceeded the influent levels for several weeks, indicating that desorption of the compound was occurring.

In the Connecticut pilot study, the predominant compound was 1,1,1-trichloroethane, at concentrations ranging from 10 to 50 ug/L. Trichloroethylene (less than detection limits to 10 ug/L) and cis-1,2-dichloroethylene (less than detection limits to 4 ug/L) were also present. The test columns (containing Filtrasorb® 400 GAC) were sampled weekly for 1 year, then allowed to run continuously and resampled 1 year later. 1,1,1-Trichloroethane and cis-1,2-dichloroethylene appeared in the effluent after approximately 12 and 22 weeks, respectively (Figure 4-3). Trichloroethylene was removed to below the detection limit (0.1 ug/L) for the entire first year, but the GAC was exhausted after 2 years (Figure 4-4).

New Jersey--A study conducted by EPA to determine the effect of aeration followed by adsorption was conducted in New Jersey on a water contaminated with 1,1,1-trichloroethane. The performance of GAC (Witcarb® 950) before and after aeration is shown in Figure 4-5. In this study, breakthrough of 1,1,1-trichloroethane occurred after approximately 32 weeks in the column treating unaerated water but did not occur even after 60 weeks for the aerated water.

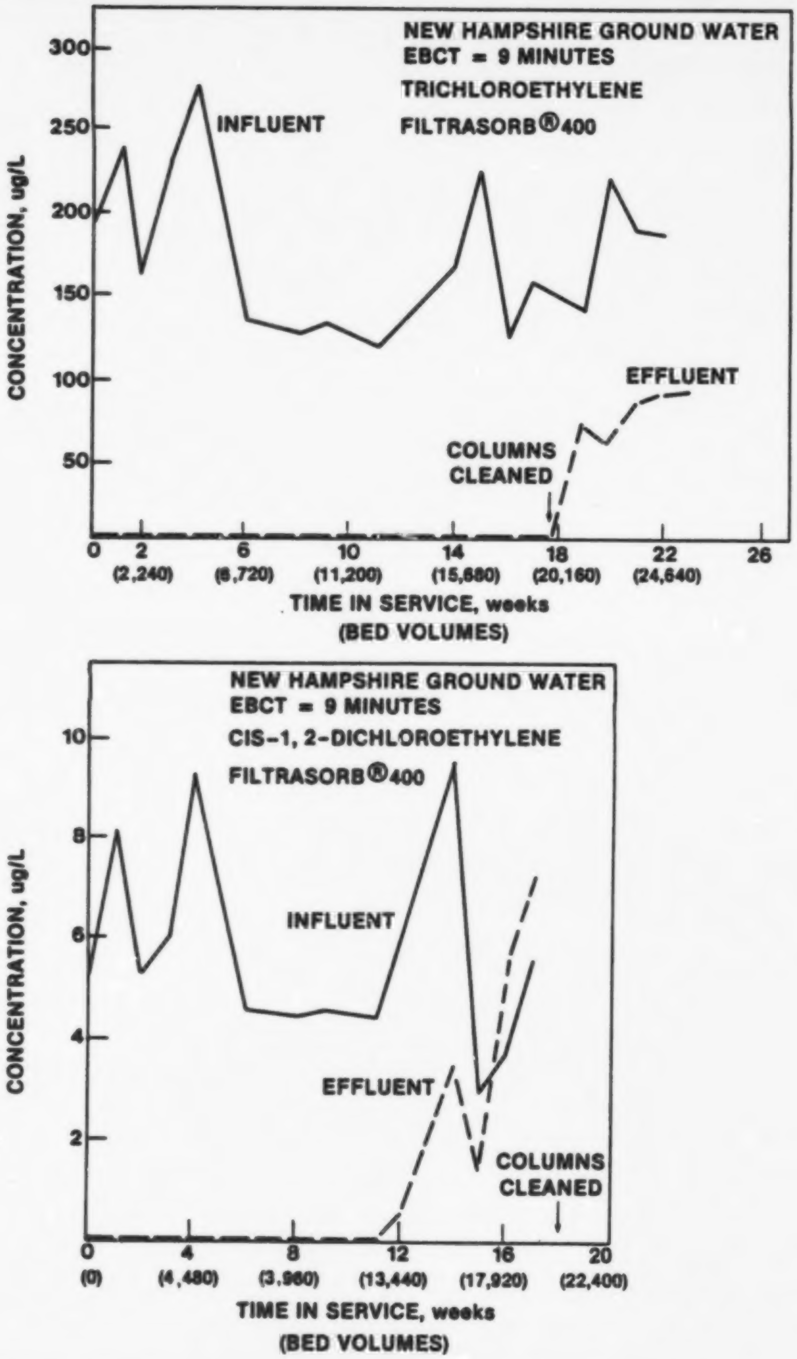

Figure 4-2
PERFORMANCE OF GAC FOR REMOVING TRICHLOROETHYLENE AND CIS-1,2-DICHLOROETHYLENE FROM A CONTAMINATED WATER SUPPLY IN NEW HAMPSHIRE
SOURCE: LOVE AND EILERS, 1982.

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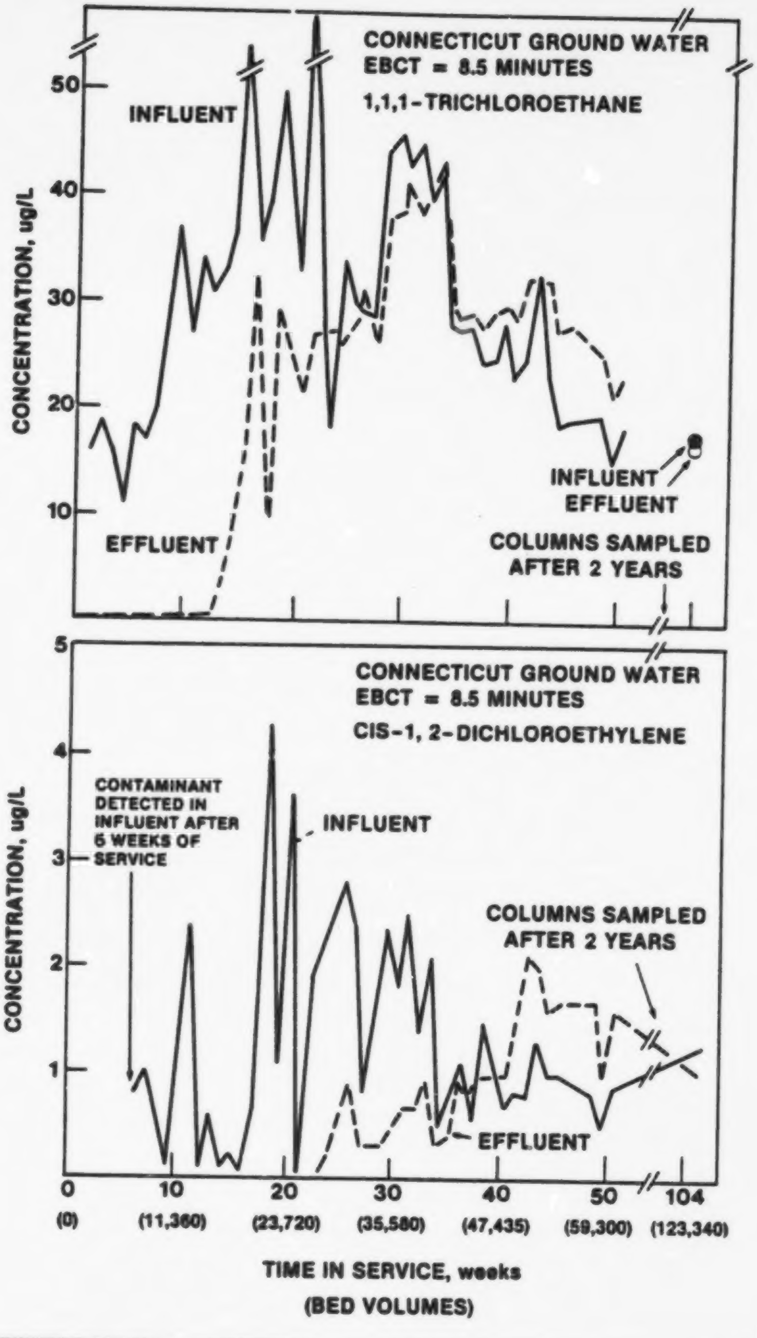

Figure 4-3
REMOVAL OF 1,1,1-TRICHLOROETHANE AND CIS-1,2-DICHLOROETHYLENE BY ADSORPTION ON GAC

SOURCE: LOVE AND EILERS, 1982.

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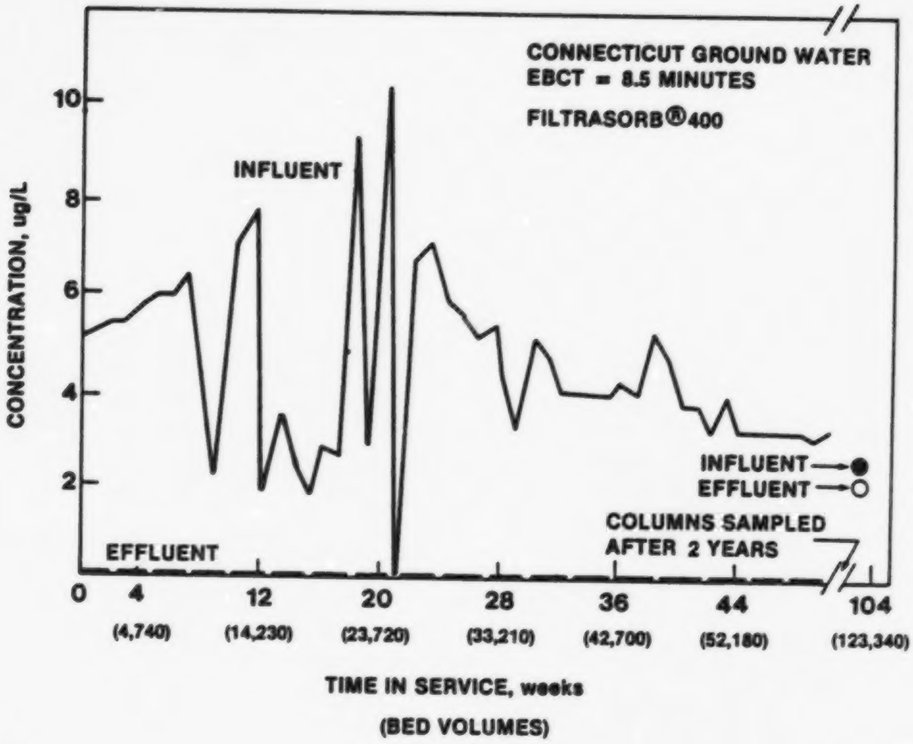

Figure 4-4
REMOVAL OF TRICHLOROETHYLENE BY ADSORPTION ON GAC

SOURCE: LOVE AND EILERS, 1982.

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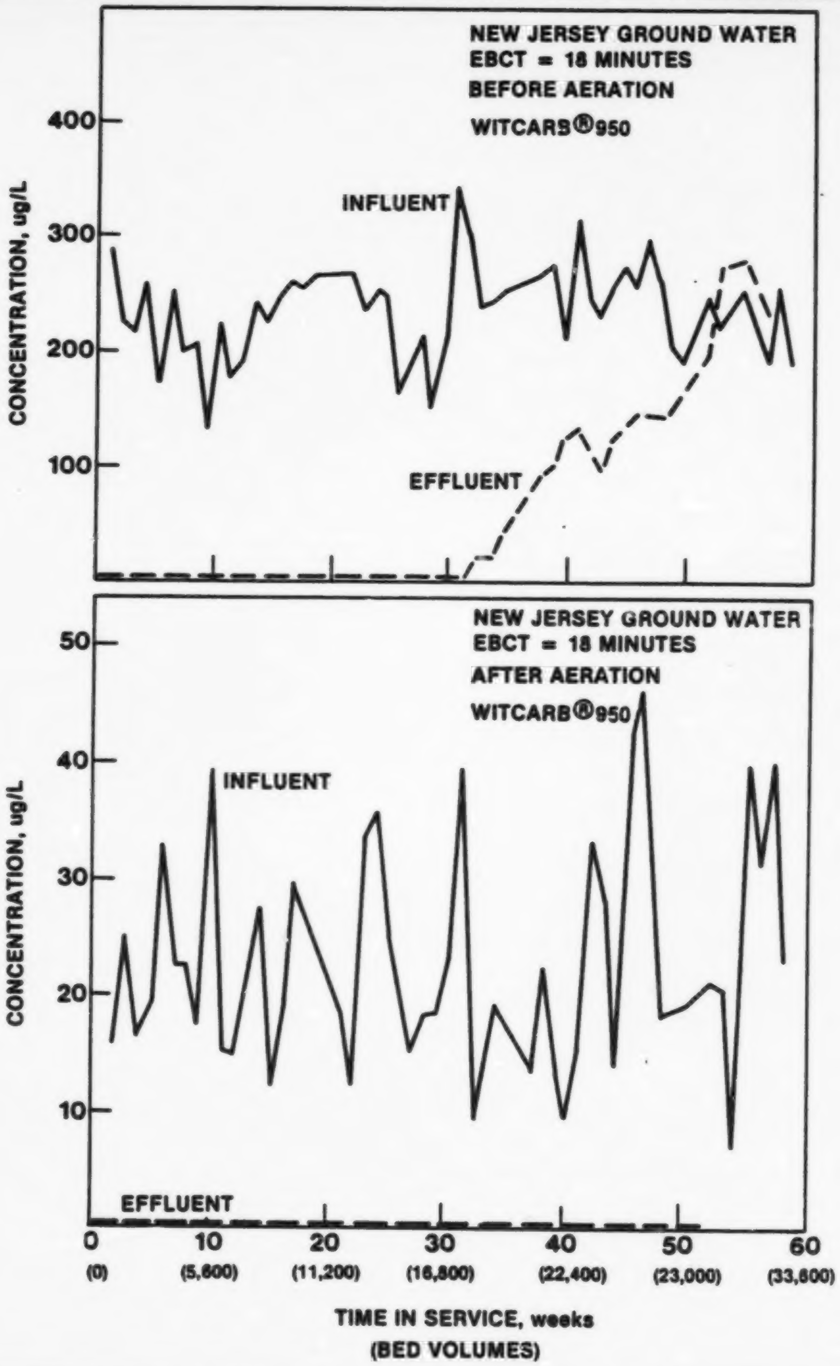

Figure 4-5
REMOVAL OF 1,1,1-TRICHLOROETHANE BEFORE AND AFTER AERATION ON GAC

SOURCE: LOVE AND EILERS, 1982.

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Full-scale carbon systems for removal of VOCs have been successfully utilized in treatment of several potable water supplies. Several of these applications are described in the following paragraphs.

North Penn Water Authority--The North Penn Water Authority of Lansdale, Pennsylvania, is a typical example of the small community ground water contamination problem. Several GAC pressure filters were installed for treatment of the authority's water supply in November 1981 after trichloroethylene and traces of tetrachloroethylene were discovered in the raw water. Raw water concentrations of trichloroethylene from the well field ranged from approximately 20 to 130 ug/L.

The GAC adsorption system installed consisted of two 5-foot-diameter steel vessels approximately 14 feet high with 10-foot straight sidewalls (North Penn Water Authority, 1982). The columns were operated in series with an EBCT of 7.5 minutes per vessel. Additional housing capacity was added to the existing pumphouse to protect the system and operators during cold weather. A schematic diagram of the system is shown in Figure 4-1.

The total cost for the system, including purchase of filters and related piping, miscellaneous piping changes, and construction of the pumphouse addition, was approximately $70,000 (1981 dollars).

Because the system was relatively small, a clearwell for storing backwash water was not added. Backwashing of the filters was necessary approximately every 6 months. Backwashing was performed by pumping water directly out of the distribution system into the underdrain system of the contactors. Waste backwash water was discharged to the sanitary sewer.

The trichloroethylene concentration in the effluent from the first contactor reached 4.5 ug/L (the State of Pennsylvania's recommended maximum level) on January 5, 1982, 2 months after installation, and exceeded this value in the effluent from the second reactor on June 1, 1982. Trichloroethylene concentrations in the raw water and effluents from the first and second contactors are shown in Figure 4-6.

After 1 year of operation, the total cost of water production was estimated by the authority to be 30¢/1,000 gallons higher than the cost prior to the installation of the treatment system. Of this total, the cost of amortizing the capital investment over a 20-year period with a 12-percent interest rate was estimated at 18¢/1,000 gallons, and the cost of replacing the carbon every 6 months and performing weekly monitoring was estimated at 12¢/1,000 gallons (North Penn Water Authority, 1982).

Rockaway Township, New Jersey--Rockaway Township, New Jersey, experienced a more complex ground water contamination problem. The township obtained its water from three wells, approximately 60 feet apart and 100 to 200 feet deep, which tapped an aquifer in an unconsolidated glacial deposit. In early 1980, the township discovered trichloroethylene in two of its three public wells which served about 11,000 persons, or about half the township population. The levels of trichloroethylene in the two wells ranged from 50 to 100 ug/L in one well and from 170 to 220 ug/L in the other well (Industrial Waste Engineering, 1981).

Following the discovery of the contamination, the two wells were taken out of service. The third well continued to supply the township's needs. In October 1980, acting on complaints about taste and odor, the township had additional laboratory analyses performed on the third well. Two potentially toxic organics, diisopropyl ether and methyl tertiary butyl ether, were found in the water. As a result, a water emergency was declared, and treatment methods for removing these contaminants were evaluated.

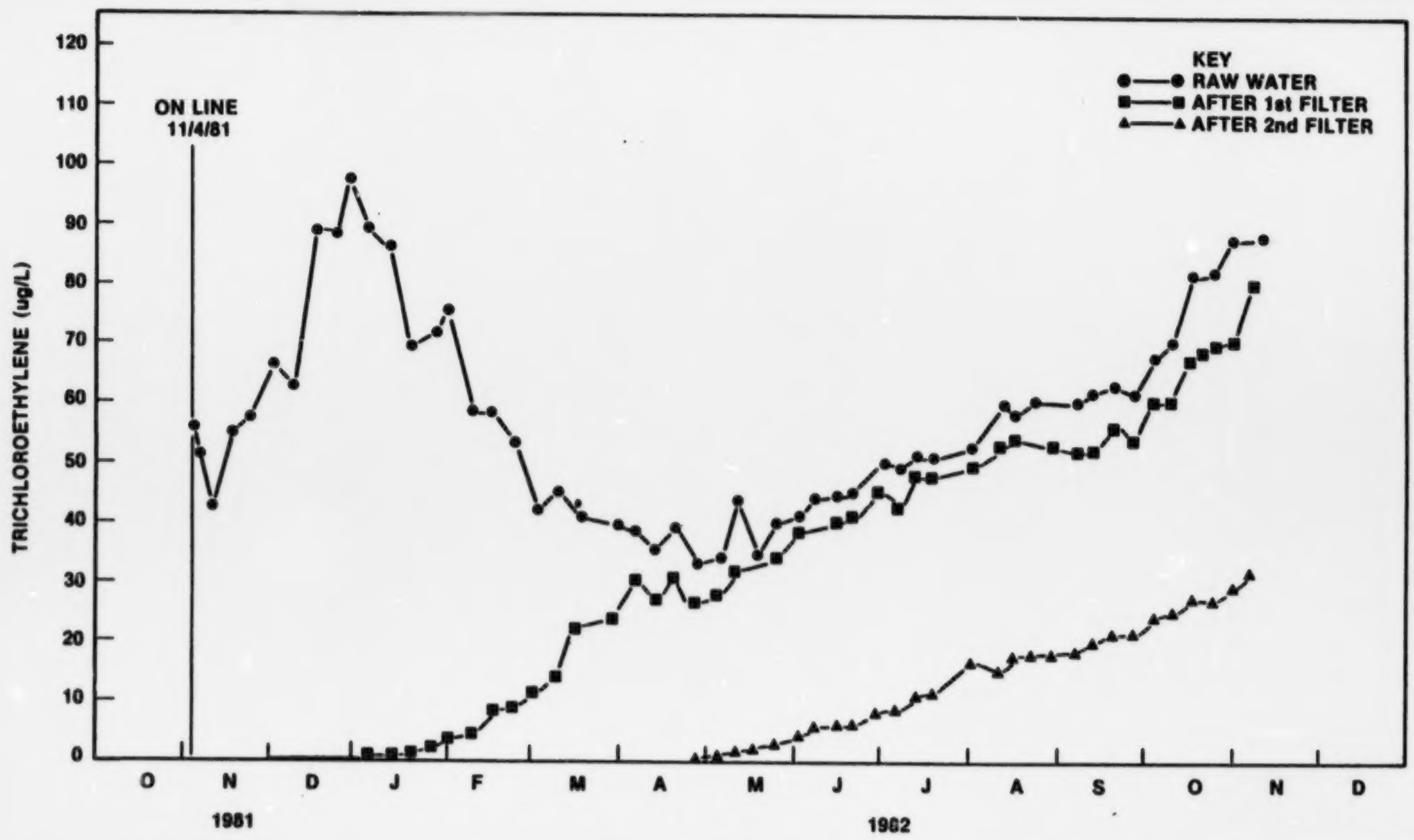

Figure 4-6
TRICHLOROETHYLENE BREAKTHROUGH AT NORTH PENN WATER AUTHORITY GAC TREATMENT PLANT

SOURCE: ESE, 1982.

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A granular carbon adsorption system was selected as the quickest and most effective way of ending the water emergency. Within approximately 1 month, a GAC system was placed in operation, and all three wells were put back in service. The GAC system consisted of two downflow pressure contactors operated in parallel. Each contactor was 10 feet in diameter, 20 feet high, and held 20,000 pounds of carbon. Contact time in the contactors was 12 minutes, at a design flow rate of 1,000 gpm. The GAC system was housed to protect it and plant operators during cold weather (McKinnon and Dyksen, 1984).

Initially, the carbon life was expected to be between 6 and 8 months. However, after 4 months of operation, diisopropyl ether and methyl tertiary butyl ether were detected in the contactor effluent. Trichloroethylene was not detected. Due to the rapid breakthrough of the ethers, it eventually became necessary to replace the carbon approximately every 45 days, at a cost of $30,000 to $35,000 per change (McKinnon and Dyksen, 1984). A packed tower aeration system subsequently was installed as a pretreatment stage prior to treatment with GAC.

The packed tower system successfully removed greater than 90 percent of the ethers and trichloroethylene. (For further discussion of this system see Section 3.1.) The aeration pretreatment greatly increased the life of the carbon and resulted in a significant net reduction in the total treatment cost. (These results were similar to those obtained in an EPA pilot study, illustrated in Figure 4-5.)

The total construction cost of the GAC system, including the contactors, piping, building, and site work, was estimated to be $200,000 in 1980. The annual cost of replacement of carbon was estimated at $200,000 or $0.52 per thousand gallons (McKinnon and Dyksen, 1984).

5.0 OTHER TREATMENT/ALTERNATIVE TECHNOLOGIES FOR REMOVAL OF VOCs FROM DRINKING WATER

A brief process description, in addition to pilot- and full-scale case studies for Other Treatment/Alternative Technologies, is presented in the following sections.

5.1 MULTIPLE-TRAY AERATION

Process Description

Multiple-tray aerators have a series of trays with slats, perforations, or wire mesh bottoms over which water falls and eventually collects at the base of the unit. The thin film of water formed as the water flows over the media provides a large surface area for mass transfer of the VOCs from water to air. Coke, coal, stone, or ceramic balls can be placed in the trays to increase efficiency. Multiple-tray aerators are sometimes equipped with blowers, but often are open-sided depending on natural ventilation.

Case Studies

Multiple-tray aeration has been found effective in removing a significant percentage of VOCs (20 to 90 percent) from drinking water (Robeck and Love, 1983; Hess *et al*., 1981). Several full-scale evaluations are described in the following sections.

Smyrna, Delaware--An incident of ground water contamination with trichloroethylene occurred in Smyrna, Delaware, in 1978. The raw ground water was contaminated with trichloroethylene concentrations ranging from 40 to 70 ug/L. Two induced draft, slat-tray aerators existed at each well when the contamination was discovered. These redwood slat-tray aerators were originally installed for carbon dioxide removal and not for VOC removal. Thus, upon discovering the subsequent contamination, it was possible to assess their VOC removal efficiency. The water flow rate to the aerators was varied, and influent and effluent samples were obtained for trichloroethylene analysis. The results, shown in Table 5-1, indicated that aeration achieved up to 90-percent removal of trichloroethylene (Joyce, 1980), although removal

Table 5-1. Summary of Trichloroethylene Removal by Aeration at Smyrna, Delaware

Date	Well Number	Raw TCE* Concentration (ug/L)	Finished TCE* Concentration (ug/L)	Hydraulic Loading (Percent Design Flow Through Aerator)	Percent Removal
2/01	1	22.9	11.6	100	49
2/01	2	70	16	100	77
3/14	2	64.5	9.7	77.8	85
5/22	1	19.5	13	68	33
5/22	2	25	4.5	65	82
7/06	1	32	14	100	56
7/06	1	32	13	68.2	59
7/06	2	21	7	100	67
8/14	1	31	15	100	52
8/14	2	23	7.5	100	67

TCE = Trichloroethylene.

Source: Joyce, 1980.

efficiencies of 50 to 60 percent were more typical. Factors affecting the efficiency of the aerators, such as temperature and tray design were not evaluated.

Camden, New Jersey--In December 1979, the City of Camden, New Jersey, detected several VOCs in three raw water supply wells. The VOCs detected included trichloroethylene, tetrachloroethylene, carbon tetrachloride, and 1,2-dichloroethane.

The treatment plant was equipped with a 12-ft-high multiple-tray aerator with a cross-sectional area of 180 ft^2, as shown in Figure 5-1 (Hess et al., 1981, 1983). Note that Figure 5-1 is shown in the forced-air mode, whereas this installation operated in the induced-air mode. The aerator was equipped with two 5,100 cubic-feet-per-minute (cfm) blowers. When all three wells were operated at design flows and both blowers operated, the aerator achieved an air-to-water ratio of approximately 30:1.

A study was undertaken to determine the efficiency of the aeration unit for removing VOCs and the optimum operating conditions. The historic data for trichloroethylene and tetrachloroethylene are shown in Figure 5-2. Results of full-scale treatment are not shown. The efficiency of the unit varied widely under the operating conditions. Preliminary results indicated that the aerator efficiency could be improved by increasing the air-to-water ratio. In addition, several tests were performed to evaluate recirculation of the blower exhaust air. It was found that contaminated exhaust air from the blowers located at the top of the unit was being recirculated down the sides of the unit and into the air intakes, located at the base of the units, thus reducing the removal efficiency. Elimination of this recirculation increased the effectiveness of the aerator (Hess et al., 1983).

Norwalk, Connecticut--In 1979, an industrial spill occurred along the Silvermine River, which flows adjacent to a well field from which the City of Norwalk, Connecticut, obtains a portion of its water supply.

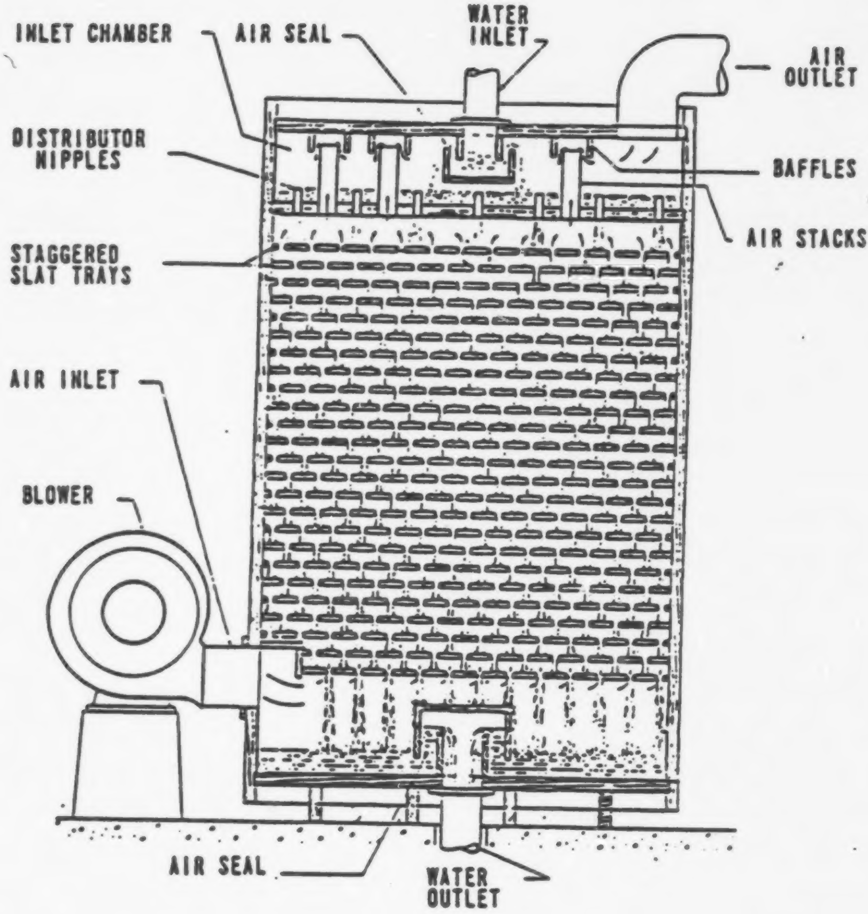
INLET CHAMBER
AIR SEAL
WATER INLET
AIR OUTLET
DISTRIBUTOR NIPPLES
BAFFLES
AIR STACKS
STAGGERED SLAT TRAYS
AIR INLET
BLOWER
AIR SEAL
WATER OUTLET

Figure 5-1
DIAGRAM OF A REDWOOD SLAT TRAY AERATOR

SOURCE: HESS et al., 1981, 1983.

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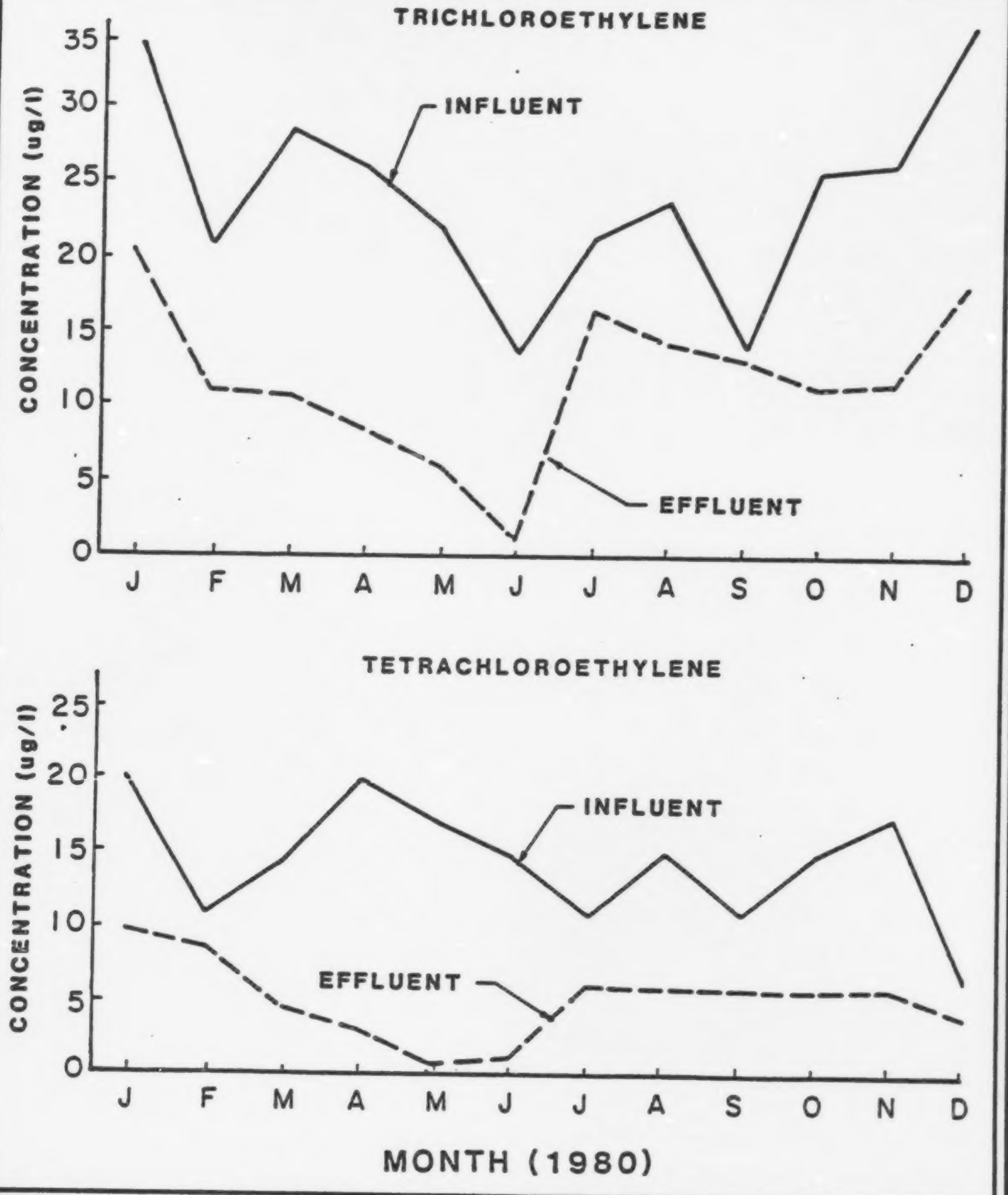

Figure 5-2
VOC REMOVALS AT CAMDEN PARKSIDE PLANT USING MULTIPLE TRAY AERATOR

SOURCE: HESS et al., 1981.

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Subsequently, the city conducted analyses for organic chemicals and detected several VOCs in each well.

The predominant compound was trichloroethylene, which was detected at concentrations of 100 to 200 ug/L in one well, 50 to 100 ug/L in another well, and less than 50 ug/L in the other two wells (Hess et al., 1981). As the trichloroethylene from the industrial spill was flushed out, the concentrations of trichloroethylene dropped to about 50 ug/L in the most contaminated well and about 25 ug/L in the other three wells. Other compounds which were detected in each well at concentrations of less than 5 ug/L include tetrachloroethylene, 1,2-dichloroethylene, 1,1,1-trichloro- ethane, trans-1,2-dichloroethylene, and 1,1-dichloroethylene.

To remove the organic contaminants from the ground water supply system, the district used a combination of treatment and source control strategies:

1. The well with the highest concentration of organic contaminants was kept out of service, as this well had been used infrequently in the past;
2. The well with the next highest concentration of organic contaminants was modified to include an aeration unit to remove organic contaminants; and
3. Blending the treated water from the aeration unit with the water from the remaining two wells resulted in a trichloroethylene concentration of less than the state-recommended maximum concentration of 25 ug/L.

The aeration unit installed by the district was a multiple-tray unit similar to that used by Camden, as previously described. The unit was 16 ft high and had a cross-sectional area of 100 ft^2. Two 3,850-cfm blowers provided air to the unit. Trichloroethylene removals averaged 50 to 60 percent, while the percent removal of the other compounds varied.

5.2 DIFFUSED AERATION

Process Description

Diffused aeration is the bubbling of air into a water-filled contact chamber through a diffuser mechanism usually located at or near the bottom of the chamber. The chamber can be either a column or basin. It is also possible to install air diffusers and piping in existing storage tanks or reservoirs, if an open basin is unavailable.

One advantage of diffused aeration is that existing basins such as a chlorine contact or recarbonation basin may be retrofitted with diffusers and converted to aeration basins, thus eliminating the need for new basin construction. The suitability and effectiveness of diffused aeration for a particular application should be tested on a pilot-scale level to determine its effectiveness and applicability prior to installation of a full-scale system.

The efficiency of diffused aeration for removing organics is dependent on several factors, including diffuser type, air-to-water ratio, depth of the water in the contact chamber, detention time, and water temperature.

Case Studies

Several full-scale and pilot-scale diffused aeration projects are described in the following sections.

Bristol Borough, Pennsylvania--A full-scale diffused aeration system was installed toward the latter part of 1981 at Bristol Borough, Pennsylvania, to reduce the concentration of tetrachloroethylene and trichloroethylene. An existing multiple-tray aerator was removing trichloroethylene from an influent concentration in the range of 70 to 100 ug/L to approximately 20 ug/L and tetrachloroethylene from an influent concentration in the range of 200 to 300 ug/L to approximately 70 ug/L. Pilot-scale tests conducted using a Kenics® static aerator indicated that diffused aeration could remove significant amounts of the contaminants.

Kenics® diffusers were installed on the floor of what was formerly the chlorine contact chamber. The chamber was 12 feet deep and provided a detention time of 20 minutes at a flow of 2 MGD. A blower capable of delivering 650 cfm was installed to provide air at an air-to-water ratio of approximately 3.5 to 1. The combined system of redwood slat-tray aeration plus diffused aeration has been achieving 90- to 95-percent removals. The effluent had a total VOC concentration of approximately 10 to 12 ug/L (Bristol Borough Water and Sewer Authority, 1982). The estimated capital cost (not including pilot testing or engineering design costs) for the diffused aeration system is $17,000 (1981 dollars).

Glen Cove, New York--Removals of several VOCs ranged from 50 to greater than 90 percent, using air-to-water ratios of 30:1, in a diffused aeration pilot study conducted at Glen Cove, New York (Ruggiero et al., 1980). Greater than 50-percent removal of cis-1,2-dichloroethylene, trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane was achieved at air-to-water ratios as low as 5:1. The authors noted that lowest concentrations of VOCs in the effluent occurred during summer when the temperatures were the highest.

Additional diffused aeration studies conducted during a subsequent phase of this project confirmed the results of the initial pilot studies. These studies used a 10-minute aeration time in a countercurrent flow aeration column. The removal efficiencies for four VOCs at various air-to-water ratios are shown in Table 5-2. Aeration was effective in removing the contaminants to below the New York State guidelines level of 50 ug/L per contaminant.

EPA-Drinking Water Research Division--EPA-DWRD conducted laboratory diffused aeration studies on waters containing trichloroethylene and

Table 5-2. Performance of Diffused Aeration at Glen Cove, New York

Air-to-Water Ratio	Contaminant	Diffused Aeration Column Avg. Influent	Avg. Effluent	Avg. % Removal
5:1	cis-1,2-Dichloroethylene	62	28	55
	Trichloroethylene	131	47	64
	Tetrachloroethylene	156	42	73
	1,1,1-Trichloroethane	4.0	1.7	58
10:1	cis-1,2-Dichloroethylene	43	14	67
	Trichloroethylene	150	40	73
	Tetrachloroethylene	85	18	79
	1,1,1-Trichloroethane	3.8	1.2	68
15:1	cis-1,2-Dichloroethylene	37	8.6	77
	Trichloroethylene	171	23	87
	Tetrachloroethylene	49	4.4	91
	1,1,1-Trichloroethane	3.7	0.7	81

Source: Nebolsine Kohlmann Ruggiero Engineers, 1982.

tetrachloroethylene. The results of these studies are summarized in Table 5-3. The pilot system consisted of a 1.5-inch-diameter countercurrent glass column approximately 4 feet long with a fritted glass diffuser in the bottom. This system was also used in a field study in New Jersey on a contaminated well supply. The results of this field study are shown in Table 5-4. The removal efficiency for a particular compound generally corresponded to its Henry's Law constant (i.e., the higher the Henry's Law constant, the higher the percent removal).

Table 5-3. Removal of Trichloroethylene and Tetrachloroethylene from Drinking Water Using Diffused-Air Aeration

Contaminant	Average Influent Concentration (ug/L)	Average Effluent Concentration (ug/L)						
		Air-to-Water Ratios						
		1:1	2:1	3:1	4:1	8:1	16:1	20:1
Trichloro-ethylene	1,064	796	614	508	319	53	—	--
	397	223	273	102	82	22	<1	<1
	241	136	110	61	53	8	2	3
	110	40	28	18	9	3	<1	<1
	73	22	14	8	6	1	<1	<1
Tetrachloro-ethylene	1,025	698	416	304	156	16	—	--
	636	161	177	46	34	8	<1	<1
	338	139	103	47	34	4	1	2
	114	32	17	7	4	<1	<1	<1
	107	32	17	7	4	<1	<1	<1
	17	3	2	1	1	<1	<1	<1

Source: Love and Eilers, 1982.

Table 5-4. Performance of Diffused Aeration on a Solvent-Contaminated Ground Water in New Jersey

Contaminant	Average Concentration (ug/L) Before Aeration	Average Concentration (ug/L) After Aeration*	Percent Removal	H†, Conc. in Air / Conc. in Water
1,1-Dichloroethylene	122	4	97	7.8
1,1,1-Trichloroethane	237	23	90	1.2
Tetrachloroethylene	94	9	90	1.1
Trichloroethylene	3	0.4	87	0.48
cis-1,2-Dichloroethylene	0.5	<0.1	>80	0.31
1,1-Dichloroethane	6	1	83	NR
1,2-Dichloroethane	1.4	0.8	42	0.05

NR = Not reported.

* Diffused-air aeration, 10-minute contact; 4:1 (vol to vol) air to water; depth = 0.8 m.

† From Table 3-1.

Source: Love and Eilers, 1982.

5.3 SPRAY AERATION

Process Description

Spray aeration is the production of small water droplets by spraying water through nozzles. The small droplets produced expose a large interfacial surface area through which VOCs can migrate from the liquid (water) phase to the gaseous (air) phase.

Case Studies

Florida--A private industrial plant, located in southern Florida, installed a spray aeration system to clean up a contaminated aquifer. The predominant contaminant present in the ground water was 1,1-dichloroethane. Trichloroethylene, tetrachloroethylene, vinyl chloride, and 1,1,1-trichloroethane were also present. The total VOC concentration varied from 100 to 200 ug/L.

The system consisted of four aeration stages. Each stage obtained approximately 90-percent total VOC removal. Twenty spray heads per stage were used. Pressure drop through the spray heads was approximately 10 pounds per square inch (psig). All four stages operated in series obtained greater than 99.9-percent removal of VOCs.

United States--As a temporary measure while a packed tower aerator was being designed, one United States water facility, faced with industrial solvent contamination, suspended a 10-cm-diameter pipe grid inside the top of one of their above ground steel storage tanks (Robeck and Love, 1983). This grid had some spray nozzles, but it also had a pattern of slits cut with a welding torch. The storage reservoir hydraulically floated on the distribution system, so a separate pump was installed to recirculate the stored water continuously through the spray grid. This energy intense arrangement resulted in 50- to 70-percent removals of trichloroethylene.

5.4 AIR-LIFT PUMPING

Process Description

In an air-lift pump compressed air is forced through an air pipe down into a well tube and discharged at the bottom of the well. The fine air bubbles mix with the water, and this mixture, being less dense than the nonaerated water, rises in the eductor pipe.

Case Studies

EPA Drinking Water Research Division--EPA-DWRD (Miltner, 1984) has found through field studies that although it is more expensive to use an air-lift pump, using the well as a reaction vessel may offset the capital cost of an above ground aerator. The tests conducted by EPA have shown 40- to 70-percent removal of trichloroethylene and up to 97-percent removal of vinyl chloride using the air-lift pump. Preliminary tests using in-well diffused aeration and a submersible (electrical motor) pump showed 80-percent removal of trichloroethylene.

In-well aeration has limited application. Depending on the size of the well casing and the equipment to be placed in the well, there may be a maximum air-to-water ratio limit which is insufficient to give the required percent removal. The dissolved oxygen can also reach saturation, depending on the depth to which air must be blown. In the EPA field tests (Miltner, 1984), the water appeared very milky when pumped to the surface. This was due to saturation with dissolved oxygen. This situation was corrected by the addition of an open quiescent basin for the release of the dissolved oxygen. High dissolved oxygen can be corrosive to metallic distribution pipes.

5.5 POWDERED ACTIVATED CARBON (PAC)

Process Description

PAC is most frequently used for taste and odor control in conventional coagulation/filtration plants treating surface water, although occasionally ground water plants equipped with softening basins have used PAC. PAC can be added either through dry feed machines or as a carbon slurry. The application point is dependent on a number of interrelated factors that must be evaluated in terms of the overall treatment scheme. Sufficient contact time, proper mixing, effects of chlorine and other chemicals, and the removal method of spent PAC are a few of the factors which should be considered before PAC is applied.

Case Studies

Ohio River--A sudden increase of carbon tetrachloride concentration in a tributary to the Ohio River during early 1977 furnished an opportunity to study the removal of this VOC by PAC adsorption. Bench-scale studies at the EPA laboratory in Cincinnati were conducted using untreated river water containing approximately 70 ug/L of carbon tetrachloride. This water was dosed with varying amounts of PAC, mixed rapidly for 1 minute, and then contacted (slow mix) for 1 hour in a jar test apparatus. Under these conditions, the largest PAC dose of 30 mg/L resulted in a removal of 20-percent of the carbon tetrachloride in the raw water. Some of the 20-percent removal was probably due to volatilization in the rapid mixing phase.

During this period, several water treatment plants using the Ohio River as a source water were adding PAC. At the Cincinnati, Ohio plant, a total of approximately 9.6 mg/L of PAC was added in two stages. Using conventional treatment and this PAC dosage, little difference between the source and finished water concentrations was noted (Seegar *et al*., 1978). The City of Evansville, Indiana, was also adding up to 21 mg/L PAC at this time for control of carbon tetrachloride (Rexing, 1978). Consistent removals were not obtained (i.e., finished water carbon tetrachloride concentrations sometimes exceeded influent concentrations). On the average, however, a 25-percent removal of carbon tetrachloride was accomplished for this time period.

North Miami Beach--Another opportunity to evaluate PAC on a plant-scale basis occurred when synthetic organic contamination was discovered in well fields within the Biscayne Aquifer which supplies water to the City of North Miami Beach. Studies were undertaken to investigate the use of PAC as a short-term alternative treatment to GAC (ESE, 1978). The North Miami Beach well field contained eight wells connected by a manifold to the main raw water transmission line that supplies the Sunny Isles Water Treatment Plant, a conventional lime softening plant. PAC was added to the water at the well field to maximize contact time. Feed rates were 7.1, 7.9, 14.3, and 26 mg/L. Total contact time for both the transmission line and plant was estimated to be approximately 2 hours with an average plant flow of 10.4 MGD. Additional studies on PAC at the plant showed that 7 mg/L PAC removed 40 to 65 percent of the 10 to 24 ug/L of 1,1,1-trichloroethane with recarbonation that was present (ESE, 1979).

5.6 WELL FIELD MANAGEMENT

Process Description

Well field management refers to a group of water management options which can be used by a water supply which obtains its water from several sources, such as multiple wells or a combination of wells and surface water sources. Contamination may only occur in a small number of wells in a large well field. In this case, it is possible to manage well pumping to meet the MCL.

Management strategies which can be used include eliminating the use of the contaminated source(s), reduced use of the contaminated source, blending with uncontaminated or slightly contaminated sources such that the blended water meets the MCL for the particular contaminants, or, with ground water sources, use of an interceptor well pumped to waste to prevent the contaminants from migrating toward the source wells by maintaining the necessary hydraulic gradient. Several communities have managed to solve VOC contamination problems by using well field management.

Case Studies

Bucks County Pennsylvania--Two utilities in Bucks County, Pennsylvania, the Chalfont Borough Water Works and the Keystone Water Company, each found low-level concentrations of VOCs in their wells. Both utilities had sufficient additional uncontaminated wells to control the problem simply by taking the affected wells out of service (Hess et al., 1981).

Kalamazoo, Michigan--In late 1980, tetrachloroethylene was detected in the water supply of Kalamazoo, Michigan (Minsley, 1983). Additional sampling led to identification of the contaminated source. Two wells were pumped to waste. This was apparently successful in preventing the contamination from spreading to other wells in that well field.

Dade County, Florida--The Biscayne Aquifer Management Program in Dade County, Florida, is one of the more comprehensive aquifer management programs developed to date. It is an example of a cooperative effort of local, state, and federal agencies to control VOC (and nitrate) ground water contamination by careful management of water resources and proper land use and waste disposal (Yoder *et al.*, 1981).

The Biscayne Aquifer is the only source of potable water in the Miami area. Urban development brought increased demand on water quantity and quality in Dade County. Initially, extensive drainage work for land development and hurricane flooding protection resulted in lower ground water levels and allowed saltwater intrusion in the coastal areas, along uncontrolled canals, and around eastern well fields. Salinity dams, proper management of coastal construction, and relocation and management of water supplies reduced the threat of continued saltwater intrusion. In the mid 1970s, additional ground water problems were identified, including high levels of nitrates in surface and ground waters and the presence of VOCs in the ground water.

Studies on the extent and type of VOC contamination were performed. Additional studies were conducted to relate VOC contamination to land use. Table 5-5 shows the total combined average concentration of volatile synthetic organic compounds related to the land uses around the test sites.

The threat of ground water pollution from industrial land uses plus documented cases of biological contamination of public water supply wells led to the development of a "well field protection" ordinance by the Department of Environmental Resources Management. This ordinance regulates land uses within the cones of influence of all public water supply wells in the county. Restrictions are based on the computed ground water (hydraulic) travel time between a proposed development or activity and the water supply well. No development is permitted immediately adjacent to a well. Density is restricted according to projected sewage flows (effluent from septic tanks or exfiltration from sewers). Stormwater and wastewater disposal facilities also are

Table 5-5. Average Level of Contamination at Ground Water Sampling Sites*

Prevailing Land Use, Listed in Ascending Order of Intensity	Volatile Organic Contamination (ug/L)	Range
Undeveloped	0.0	None detected
Undeveloped	0.0	
Residential	0.1	
Residential, canal, industrial	0.4	
Residential, commercial	0.5	Low
Residential, commercial, industrial	0.8	
Residential	1.0	
Residential, canal, industrial	1.6	
Residential, commercial, industrial	1.6	Moderate
Industrial	2.7	
Residential, commercial, canal	4.6	
Industrial, residential	13.1	
Residential, industrial	20.0	High
Utility, residential, industrial	48.7	
Industrial, residential	57.3	

* Each value represents a different sampling site.

Source: Yoder *et al*., 1981.

restricted. No additional activities involving the use of hazardous materials are permitted with a 210-day hydraulic travel time. Existing uses are subjected to a more rigorous monitoring and enforcement program.

Hydraulic travel times have been established on the basis of measured drawdowns, some modeling, and the application of the best available data. In some cases, the cones of influence are based on theoretical computations, because no direct measurements have been made. All cones of influence are projected for the maximum permitted pumpage rate. The 210-day travel time represents the longest recorded period without recharge from rainfall. Thus, a worst-case condition is represented in terms of water demand and a diminished capacity for dilution of contaminants.

5.7 REGIONALIZATION

Description

One alternative to treatment of VOC-contaminated water which is especially attractive to some small water systems is to join with other small or large systems to form a regional water supply system. Regionalization provides a mechanism for attaining MCL compliance. Some systems that are required to install additional treatment to meet the MCLs will experience significant cost increases. Installation, operation, and maintenance of more complex control processes, together with monitoring requirements, all result in product cost increases to the consumer. Examination of these costs and their impact could influence a water system to consider regionalization.

5.8 BOTTLED WATER

Description

Bottled water is sold throughout the United States, and in 1977, an estimated 400 million gallons of bottled water were sold at a cost of about $160 million. Sales have been rising at a rate of 10 to 12 percent per year. California accounts for about 50 percent of the sales, while Florida, Illinois, New York, and Texas account for an additional 37 percent. Currently, the industry is composed of approximately 500 individual bottlers, with route delivery the predominant means of distribution (Bauman and Dworkin, 1978).

In regulating the bottled water market, the Food and Drug Administration (FDA) has established standards for turbidity, color, odor, chemical composition, and radiological quality [FDA/Health, Education, and Welfare (HEW), 1973]. Manufacturing practices also include requirements for testing and approval of the product water source and for coding and monitoring the distribution of the bottled water (FDA/HEW, 1975). Bottled water sold in grocery markets, usually spring or demineralized water, sells for between $0.50 and $1.50 per gallon.

Case Studies

In 1973, bottled water was used to augment the public water supply in Duluth, Minnesota. A special survey to determine how the citizens of Duluth coped with asbestos contamination in the water supply revealed that 47 percent used the contaminated tap water without further treatment, while 53 percent used alternative sources of water for potable use. Of those using alternative water sources, 51 percent used specially filtered water available at public buildings throughout the city, 29 percent obtained water from wells, 6 percent used filtering devices in the home, and 6 percent used bottled water. The remaining 8 percent obtained water from other sources (rural wells, rain barrels, etc.) and water from adjoining cities, such as Superior, Wisconsin, which was free of asbestos contamination (Bauman and Dworkin, 1978).

5.9 ALTERNATE SOURCE

Description

Development of alternate water sources located within a reasonable distance of a community which do not exceed the MCL for VOC contaminants may provide a satisfactory solution to a water quality problem. Since the majority of the systems with VOCs exceeding the MCL are from ground water sources, available surface water sources are likely options as alternate sources. Although the surface sources may be free of the contaminants, they may require treatment, such as clarification and disinfection, which may be as expensive as removing the contaminant from the original source water. However, the VOC contaminants in the original source may be confined to a localized aquifer source, and developing wells of different depths and at different locations should be considered. In any event, alternate surface water or ground water sources may be available depending on the size and location of the system and the costs involved. Smaller communities tend to use ground water sources because, in general, they do not require filtration. Larger communities, because of the quantity of water required, tend to use surface water sources or a combination of surface and ground water sources.

6.0 ADDITIONAL TREATMENT TECHNOLOGIES FOR THE REMOVAL OF VOCs FROM DRINKING WATER

A brief description and case studies (where applicable) for Additional Treatment Technologies are presented in the following sections.

6.1 POINT-OF-USE AND POINT-OF-ENTRY

Point-of-use and point-of-entry treatment methods are options that are technically feasible for the removal of VOCs and may be more economical for some systems than other treatment methods. However, there are major areas of concern regarding the effectiveness and suitability of these units for VOC removal.

6.1.1 Home Carbon Adsorption Units

Process Description

In recent years, several manufacturers have begun marketing a variety of small carbon adsorption units designed for use in the home, office, or other point-of-use/point-of-entry consumptive applications. Two general types of home carbon adsorption units are considered here. The first is a line-bypass unit or point-of-use device designed to treat only a portion of the total flow in a household, primarily water used for drinking and cooking. These units fit beneath the kitchen sink. A portion of the incoming flow is diverted to the treatment unit. The average contact time in these units is approximately 1 minute. The second is a unit designed to treat the entire home flow or point-of-entry device. This unit is located at the point-of-entry of the home water supply. The average contact time in these units is approximately 1 minute. Various claims have been made for these units, including removal of taste and odor, purification, removal of trihalomethanes (THMs) and other organic compounds, and filtration of suspended particles. The amount of scientific data available for these units regarding removals of VOCs is, unfortunately, severely limited. Claims made by some manufacturers may be either unsubstantiated or valid for only a short period of time, usually immediately after installation of the units.

Case Studies

New Orleans, Louisiana--The most comprehensive investigation conducted to date regarding the effectiveness of these units was performed under the direction of the EPA ODW (Perry et al., 1981). The project was conducted in several phases. In the first two phases, a total of 31 various carbon units was tested for their removal efficiency for THM, non-purgeable total organic carbon, and carbon tetrachloride from New Orleans tap water. In addition, standard plate count, endotoxin data, and free and combined chlorine analyses were obtained to assess microbiological impact of the units. Several different types of filters were tested, including stationary, faucet-mount, pour-through, and line-bypass models. Phase 3 included testing ground water spiked with several VOCs, specifically carbon tetrachloride, trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane, at concentrations of 20, 50, 50, and 50 ug/L, respectively. An additional study was performed on surface water spiked with p-dichlorobenzene (10 ug/L) and hexachlorobenzene (10 ug/L). Table 6-1 shows a summary of the results for removal of these compounds. Several units, particularly the line-bypass type, consistently achieved substantial reduction in these compounds when operated within their rated hydraulic capacity. Other units were less effective.

Units which produced the highest, most consistent removals of VOCs generally had larger quantities of carbon and relatively longer contact times. This is consistent with general carbon adsorption principles.

However, it should be noted that the carbon contact time available in these units is often less than or approximately 1 minute. Normally, carbon contact times of at least 10 minutes are recommended and used in the design of larger-scale carbon adsorption units for removal of VOCs. In addition, the instantaneous flow rate through the units is highly variable in a home-use application. This may tend to disrupt the adsorption wave front and lead to early breakthrough of contaminants.

Table 6-1. Range of Percent Specific Halogenated Organic (HO) Reduction for Line-Bypass, Faucet-Mount, Stationary, and Pour-Through Units in the Ground Water Study

Unit	Rated Capacity (liters/gallons)	Range of Average Percent HO Reduction						
		1	2	3	4	5	6	7
Line Bypass								
Aqualux CB-2	7,571/2,000	99-99	98-96	99-99	99-99	99-90	99-54	99-89
Continental Model 350	2,725/720	99-99	99-99	99-99	99-99	95-95	85-95	99-99
Culligan Model SG-2	15,142/4,000	99-98	99-98	99-99	99-99	77-89†	99-45†	95-83†
Everpure QC4-THM	3,785/1,000	99-99	95-99	99-99	99-99	99-99†	99-99†	99-99†
Seagull IV	3,785/1,000	98-95	98-97	98-97	98-97	99-99	99-99	99-98
Aquacell	7,571/2,000	99-93	99-95	99-98	99-97	99-96	99-80	99-89
Faucet-Mount								
Hurley Town and Country	15,142/4,000	99-93	97-94	99-98	99-99	99-92	99-50	99-79
Water Washer Model 1000	3,785/1,000	96-40	95-55	95-70	99-62	99-60	50-20	96-60
Pour-Through								
Filbrook*	1,136/300	99-72	98-82	95-94	99-98	99-75	99-40	99-45
Stationary								
Sears Taste and Odor	11,356/3,000	98-70	98-80	99-96	99-98	79-88	51-30	78-35

1 = 1,1,1-trichloroethane.
2 = carbon tetrachloride.
3 = trichloroethylene.
4 = tetrachloroethylene.
5 = p-dichlorobenzene ($C_6H_4Cl_2$).
6 = hexachlorobenzene (C_6Cl_6).
7 = chlordane (Technical grade, 60 percent).

* Filbrook was tested for 1,893 liters (500 gallons), but results are adjusted to 1,136 liters (300 gallons) as being more representative of claimed lifetime.

† Units plugged prematurely.

Note: Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Source: Perry et al., 1981.

One additional area of concern regarding these home units is a possible increase in the amount of bacteria in water passing through these filters. Because activated carbon reduces the concentration of free chlorine in a water, and because the activated carbon can provide an excellent habitat for the proliferation of bacteria, these concerns must be addressed.

Research Studies

Several studies have been conducted concerning the potential high bacterial growth and accompanying byproduct release. The conclusions from these studies have varied widely. Fiore and Babineau (1977) concluded that both home carbon filtered and unfiltered water responded bacteriologically to the same extent when left standing overnight, that is, both waters had much higher bacterial concentrations in the morning. Bacterial counts were reduced substantially in both filtered and unfiltered lines by flushing the lines for 5 to 10 minutes in the morning or after long periods of non-use. Wallis *et al*. (1974) reported substantial growth rates of bacteria supported on activated carbon and attributed this growth to the localization of both seed bacteria and nutrients in the carbon particle. They also found that marked bacterial growth during quiescent overnight periods occurred resulting in large bacterial counts in the initial water passing out of the filter in the morning.

Johnston and Burt (1976) tried to verify the Wallis conclusion and to determine the fate of pathogenic bacteria using the coliform strain for their tests. Their results indicated that pathogenic bacteria (as represented by the coliform group) do not flourish in the filter environment. They concluded, "Bacteria indigenous to tap water are able to multiply quite well on compounds concentrated from tap water by charcoal filters; however, other types of bacteria such as coliform bacteria may not fare as well."

Results of EPA testing of home adsorption units showed that there may be a moderate and variable effect of activated carbon home units on bacterial levels. However, no consistent pattern was determined; in these tests, consecutive samples could produce samples with bacterial populations lower or higher than control, non-filtered samples.

In summary, the preceding studies suggest that bacteria may multiply under conditions found in a home water treatment unit attached to a drinking water tap. There are numerous parameters which may affect the amount of growth; e.g., free chlorine levels, water usage, temperature, type of material adsorbed on the carbon, and possibly impregnation of the carbon with silver.

In a study of a variety of home carbon adsorption devices, no significant difference was found in heterotrophic plate count microorganism concentrations or in the concentrations of bacterial endotoxins (Perry _et_ _al_., 1981) between silver impregnated and non-silver impregnated activated carbon units. It was also noted that silver impregnated carbon did not result in the treated water exceeding the interim primary drinking water MCL for silver of 50 ug/L.

6.1.2 Home Reverse Osmosis Units

Process Description

Home reverse osmosis (RO) treatment units currently are available in under-the-counter units to treat a portion of the delivered water. Several manufacturers are available to ensure competitive capital costs and strong warranties. The under-the-counter RO units can effectively treat up to 5 gallons per day using normal system pressures. For larger capacities, booster pumps will be required to increase the operating pressure across the RO membrane. Servicing is dependent on water quality and quantity used, at which time the membrane might be chemically cleaned or replaced. RO provides other water quality benefits, such as the reduction of salinity and hardness and the removal of other contaminants that may be present. A typical under-the-counter RO treatment unit consists of a 5-micron pre-filter, a carbon filter, the RO membrane module, and a treated water reservoir.

Several point-of-use RO manufacturers have developed and marketed small-scale RO units suitable for in-home use. Dealerships have typically been set up around the country to ensure the proper installation and servicing of these units. Different types of membranes and pressures can result in varying removal efficiencies.

Research Study

There is not a great deal of data on the removal efficiency of VOCs by RO treatment. A pilot study conducted for EPA by a private contractor (Perry *et al*., 1981) indicated 99-percent reduction of the VOCs 1,1,1-trichloroethane, carbon tetrachloride, trichloroethylene, tetrachloroethylene, and p-dichlorobenzene at influent concentrations of 50, 20, 50, 50, and 10 ug/L, respectively. A number of membrane types are available. The choice of membrane depends on the characteristics of the feed water such as pH and chlorine residual, as well as desired removal efficiency.

Recent laboratory studies (Sorg and Love, 1984) using cellulose and nylon amide membranes have shown less than 25-percent rejection of volatile organic compounds. A thin film composite membrane, on the other hand, looked very encouraging in short duration (less than 4 hours) tests for removing VOCs. However, when the thin film composite membrane was exposed to contaminaned ground water for a longer term, certain VOCs, primarily unsaturated and aromatic compounds, permeated the membranes within 12 to 16 hours. Thus, the future for RO in controlling VOCs is uncertain.

7.0 TREATMENT COSTS FOR VOC CONTROL

Capital and operating costs for the treatment technologies developed in this analysis were established based upon meetings and discussions with staff members from EPA ODW, EPA WERL, other EPA ODW contractors developing Cost and Technology documents, past experiences, and equipment manufacturers' price information. The costs for certain technologies for new systems were determined from equations developed by MERL using the computer model and updated information, where possible, written for EPA by Culp/Wesner/Culp and presented in EPA publications (EPA, 1979).

All capital costs are presented as total cost based on an extrapolated Engineering News Record (ENR) average Construction Cost Index (CCI) for 20 United States cities. Operating costs are based on a Producer Price Index (PPI) for 1983 dollars. Other general cost considerations are listed in Table 7-1 (see page 7-29). For the purpose of estimating costs per 1,000 gallons, most capital costs were amortized over 20 years at a 12-percent interest rate. Some capital costs, such as motors and blowers, were amortized over a shorter time period.

For all treatment technologies, designs and unit costs should be considered as preliminary, to be used for comparison among various technologies for planning purposes only. For a particular application, more complete and detailed designs and cost estimates should be developed based on pilot-plant testing and site-specific considerations.

Cost estimates for the technologies identified have been developed based on the information presented above. Costs were not developed for certain technologies due to insufficient full-scale evaluations and incomplete design input necessary for cost estimating. Cost estimates were developed for the following technologies:

1. Packed tower aeration,
2. Granular Activated Carbon (GAC) adsorption,
3. Multiple-tray aeration,

4. Powdered Activated Carbon (PAC) adsorption,
5. Well field management,
6. Regionalization,
7. Bottled water,
8. Alternate source,
9. Line-bypass (point-of-use) home carbon adsorption,
10. Whole (point-of-entry) home carbon adsorption, and
11. Line bypass (point-of-use) home reverse osmosis.

7.1 MOST EFFECTIVE TREATMENT TECHNOLOGIES

Cost estimates and assumptions for the Most Effective Treatment Technologies for the removal of VOCs are presented in the following sections.

7.1.1 Packed Tower Aeration

Cost estimates for packed tower aeration were developed using a design and cost optimization model developed by the Technical Support Division, EPA ODW. The design model has been field verified at eight sites for trichloroethylene (Cummins, 1983). Capital costs include stainless steel column, 1-inch plastic saddle packing, stainless steel internals, blowers, pumps, air wells, piping, instrumentation, air ducts, and electrical wiring. Additional construction costs include sitework (15 percent), engineering (15 percent), contract overhead (12 percent), legal and financial costs (2.5 percent), interest during construction (6 percent), and contingencies (15 percent).

Operation and maintenance costs include energy costs for pumps and blowers, operational labor costs, maintenance costs, and administrative costs.

The Henry's coefficient assumed for estimating costs for each compound (at 12°C) is listed in Table 7-2 (see page 7-30).

System design constraints include a maximum column diameter of 10 feet, a maximum liquid loading rate of 34 gpm/ft^2, and a minimum air pressure gradient of 1/16 inch of water per foot of packing height. Air-to-water ratios for some levels of treatment for more volatile compounds are limited on the low end by the air pressure gradient limitation in the design model. Estimated costs for packed tower systems for five VOCs at the influent and effluent concentrations specified in Table 1-2 are shown in Tables 7-3 through 7-11 (pages 7-31 through 7-39). There are three rows of costs for each system size in Tables 7-3 through 7-11. The top row in each size category presents total construction costs in thousands of dollars. The middle row in each size category presents operation and maintenance costs, in thousands of dollars per year. The bottom row in each size category presents total production costs, in cents per thousand gallons.

Packed Tower Aeration Off-Gas Treatment Costs

A potential air pollution problem may result from the implementation of a packed tower aeration system for removal of VOCs. The air concentrations leaving the stack of a packed tower aerator are generally estimated to be 1 to 5 ppm.

The total mass discharged (both in the effluent air and effluent water), air-to-water ratio, and effluent air concentration for the nine VOCs for all of the operating conditions used in the development of the packed tower aeration cost section are presented in Tables 7-12 through 7-20 (see pages 7-40 through 7-48). Also included in these tables is the Threshold Limit Value-Time Weighted Average (TLV-TWA) for each particular VOC. The TLV-TWA values come from industrial hygiene practice and are for 8-hour exposures for healthy male workers. They are used here only for comparison.

As indicated in Tables 7-12 through 7-20, only vinyl chloride, 1,1-dichloroethylene, and carbon tetrachloride exceed the TLV-TWA value. The effluent air concentration for the remaining VOCs is generally an order of magnitude lower than the reported TLV-TWA value. An air dispersion computer model (Industrial Source Complex, ISC) was used to determine the VOC dispersion from the packed tower aeration system. The packed tower operating conditions for vinyl chloride and 1,1-dichloroethylene are almost identical. The output data generated from the ISC model can be applied to both VOCs.

Closer inspection of Tables 7-16 and 7-17 reveals that the TLV-TWA value was exceeded only when the influent VOC concentration was greater than or equal to 200 ug/L. The output data generated and shown in

Tables 7-21 through 7-28 (see pages 7-49 through 7-56) represent the worst-case situation of removing an influent water concentration of 500 ug/L down to an effluent water concentration of 1 ug/L. Data generated for system sizes using multiple columns for VOC removal are computed by multiplying the concentration of a single column by the number of columns in operation. Concentration profiles for five stability conditions and various windspeeds are presented in Tables 7-21 through 7-28. Assumptions incorporated into the ISC dispersion model include: a centerline wind direction, a mixing height of 1,500 meters, a temperature of 300°K, and an anemometer height of 7.0 meters.

Estimated Costs for Packed Tower Aeration Off-Gas Carbon Adsorption

Cost estimates were developed for packed tower aeration off-gas carbon adsorption units. Capital costs include a carbon adsorber, an additional blower, a duct heater (for aeration towers with air flow rates greater than 1,000 cfm), a concrete foundation, and all necessary ductwork. The following additional costs were also included to produce the total capital cost: contingencies (15 percent of capital costs), contractor's overhead and profit (12 percent of capital costs), and engineering fees (15 percent of the sum of the capital cost and contractor's overhead and profit). Operation and maintenance costs include energy costs for blowers and duct heaters, operational labor costs, maintenance material costs, and carbon replacement costs.

Carbon usage rates for trichloroethylene were estimated using a computer model and not developed from empirical data (McGinty, 1984). Duct heaters were installed to reduce the relative humidity of the air stream from 100 percent to 50 percent. The reduction of the relative humidity resulted in a doubling of the activated carbon adsorption capacity. The cost of activated carbon used for gas phase adsorption is approximately twice that of activated carbon used for liquid phase adsorption.

System sizes requiring multiple packed towers for VOC removal were assumed to install an off-gas adsorber unit for each column.

Due to the limited data pertaining to gas phase adsorption, cost estimates for off-gas treatment were developed for the removal of trichloroethylene from an influent water concentration of 500 ug/L to an effluent water concentration of only 1 ug/L. Approximately 90-percent removal of trichloroethylene from the air stream can be expected (McGinty, 1984).

Incremental capital and O&M costs for off-gas treatment for this situation are shown in Table 7-29 (see page 7-57). Capital and O&M costs for packed tower aeration plus off-gas treatment and packed tower aeration without off-gas treatment are also shown in Table 7-29. Off-gas adsorber and duct heater costs were provided in part by Calgon Corporation and McKinney & Associates (1984).

Costs presented in this section are to provide an estimate of additional off-gas treatment costs and should be considered preliminary. For a particular application, more complete and detailed designs and cost estimates should be developed based on pilot-plant testing and site-specific considerations.

7.1.2 Granular Activated Carbon (GAC) Adsorption

GAC Adsorber System Capital Costs

GAC adsorber system construction costs for system sizes less than 2.0 million gallons per day (MGD) were developed using quotes from independent carbon contactor manufacturers. The adsorbers were sized to provide a 10-minute empty bed contact time. All units were factory-assembled with cylindrical, pressurized, downflow steel contactors. All required valves and underdrains were included.

Personal communication with several GAC contactor manufacturers revealed that the quoted prices did not include costs for labor and housing (Adams, 1984; Moore, 1984). Review of package activated carbon contactor cost estimates from "Estimating Water Treatment Costs," (EPA, 1979) showed that housing and labor represented approximately 40 percent of the total GAC system construction costs. GAC systems costs developed from manufacturers were then appropriately updated.

The following additional costs were then included to produce the total construction costs: contingency (15 percent of adsorber system capital costs), contractor's overhead and profit (12 percent of adsorber system capital costs), and engineering fees (15 percent of the sum of adsorber system capital costs and contractor's overhead and profit).

GAC adsorber system construction costs for system sizes larger than 2.0 MGD were developed from an equation presented in "Drinking Water Cost Equations" (EPA, 1982a). This equation was developed from regression analysis of cost data developed and published by the EPA in "Estimating Water Treatment Costs," Volumes 1, 2, and 3 (EPA, 1979). The equation utilizes a principal design parameter, namely the GAC contactor volume in cubic feet (ft^3), the Engineering News Record (ENR) Construction Cost Index (CCI), and several secondary design parameters.

The equation used to determine construction costs is of the general form:

$$CC = K_2 \; USRT_c^{l} \; CCI^{m} \; UN^{n} \; o^{TDH} \; p^{MI} \; q^{G} \qquad (1)$$

where: CC = annual capital costs in dollars per year (\$/yr) based on an 8-percent interest rate and a 20-year amortization period;

$USRT_c$ = design parameter for capital cost, i.e., GAC contactor volume in ft^3;

CCI = ENR CCI divided by 100;

UN = number of units in a process;

TDH = total dynamic head in feet(ft);

MI = distance in miles;

G = energy gradient in sec^{-1}; and

K_2, l, m, n
o, p, and q = constants estimated from regression analysis.

The adsorbers in the seven largest system sizes (greater than 2.0 MGD) were sized to provide a 10-minute empty-bed contact time. Gravity flow contactors (essentially equivalent to gravity sand filters) were assumed. The costs include housing, carbon removal/transfer facilities, valves, pumps, piping, and instrumentation.

For many engineering purposes, a single cost index, such as the ENR CCI, is adequate to update construction costs. In the case of water treatment construction costs, especially those for carbon treatment, use of the CCI is not always recommended because the construction components used in its development are not related to those required for water treatment plants. For example, the CCI does not include process equipment or electrical equipment for instrumentation and control. For water treatment plants, the use of several other indices is often recommended; for example, the Bureau of Labor Statistics (BLS) indices in conjunction with the ENR Building Cost Index and Skilled Labor Wage Index (EPA, 1982b).

Table 7-30 (see page 7-58) shows the indices recommended for application to each of the eight construction cost components representing the major items of material and labor affecting the cost of water treatment plant construction. These indices were combined with the construction cost factors also listed in Table 7-1 (see page 7-29) to produce a weighted CCI for use in the capital cost equation above. For example the weighted CCI for gravity flow contactors for system sizes greater than 2.0 MGD is calculated as follows:

$$\begin{aligned} \text{CCI weighted} = {} & (365.8)\ 0.01 + (308.7)\ 0.14 + (317.2\ )\ 0.05 \\ & + (351.4)\ 0.03 + (365.8)\ 0.20 + (323.1)\ 0.41 \\ & + (241.2)\ 0.02 + (343.4)\ 0.14 = 331.8 \end{aligned}$$

The annual capital costs for the seven largest system sizes were computed by substituting the following indices and constants for gravity flow contactors into Equation 1:

$$\begin{aligned} K_2 &= 472.15 \\ CCI &= 331.8 \\ l &= 0.382 \\ m, n, o, p, \text{ and } q &= 1.0 \end{aligned}$$

The costs were converted to present worth costs, and the following additional costs were then included to produce the total construction costs: contingencies (15 percent of adsorber system capital costs), contractor's overhead and profit (12 percent of the adsorber system capital costs), and engineering fees (15 percent of the sum of the adsorber system capital costs and contractor's overhead and profit). Annual costs were then recalculated by amortizing total construction costs at 12 percent over 20 years. The capital costs for GAC contactors for the 12 size categories are shown in Table 7-31 (see page 7-59).

GAC Adsorber System Operation and Maintenance (O&M) Costs

O&M costs for all size categories were estimated from equations presented in "Drinking Water Cost Equations" (EPA, 1982a). These costs include components for energy (for building heating, ventilation and lighting, backwash pumping, and carbon slurry pumping during carbon replacement), maintenance materials, and labor. The equation used to estimate these components is of the general form:

$$CQ = A\ USRT^{a}$$

where: CQ = component quality;
$USRT$ = process design parameter, i.e., square feet (ft^2) of contactor area; and
A, a = empirical constants developed for GAC systems.

The units for component quality for process electricity, maintenance materials, labor, and building energy are kilowatt hours per year (kwh/yr), \$/yr, hours per year (hr/yr), kwh/yr, respectively.

For steel pressure contactors, the values for A and a, for process electricity, maintenance materials, labor, and building energy are 4.21 and 1.0354, 6.80 and 0.963, 20.10 and 0.6435, and 1344.25 and 0.8166, respectively.

For concrete gravity contactors, the values of A and a, for process electricity, maintenance materials, labor, and building energy are 4.85 and 1.0005, 31.33 and 0.683, 9.87 and 0.712, and 408.15 and 0.882, respectively.

Assumed labor rates and electrical costs are presented in Table 7-32 (see page 7-60). These O&M costs include the cost of only one annual carbon replacement for flow rates less than 2.0 MGD and no carbon replacement cost for flow rates greater than 2.0 MGD. Carbon replacement costs are addressed in the following section.

Carbon Usage Rates

As described previously, carbon usage rates in a GAC system vary for each compound and are dependent on the influent concentration, desired effluent concentration, particular carbon used, and several other site-specific factors. The carbon usage rates used for estimating costs in this report are "best estimates" for representative usage rates based on available data. The actual carbon usage rate at a specific plant for a particular VOC could vary considerably from the estimated usage rates assumed here. This required that carbon replacement/regeneration cost be estimated and added to the other O&M cost as appropriate. The carbon usage rates used here were used to develop representative costs for the purpose of comparing available VOC removal technologies.

Carbon usage rate estimates for the following VOCs were obtained from "Treatment of Volatile Organic Compounds in Drinking Water" (EPA, 1983) and Love and Eilers (1982):

Trichloroethylene
Tetrachloroethylene
Carbon tetrachloride
1,1-Dichloroethylene
1,2-Dichloroethane
1,1,1-Trichloroethane

There are a number of gaps in these data since some systems were not in service long enough to reach breakthrough or exhaustion. A large degree of variability also appears in carbon usage rates for different sites. The data on GAC usage rates are limited because most systems treating for VOC removal are using aeration versus carbon.

Since carbon usage rates for influent and effluent concentrations different from those presented in this reference were desired, a predictor equation was developed for each compound by fitting a multiple, least-squares regression analysis of the carbon usage data to the log-transformed values of effluent and influent concentrations. The predictor equation and carbon usage rates for each of these compounds are shown in Tables 7-33 through 7-38 (see pages 7-61 through 7-66).

For benzene and p-dichlorobenzene, a different approach was used, since carbon usage rates for these compounds were not included in the above reference. Freundlich parameters for benzene and p-dichlorobenzene were obtained from personnel at EPA-Municipal Environmental Research Laboratory (MERL) in Cincinnati, Ohio. The Freundlich parameters K and 1/n, used for estimating carbon usage rates for these two compounds, are:

VOC	K	1/n
Benzene	50	0.53
P-dichlorobenzene	350	0.60

The carbon usage rates for benzene and p-dichlorobenzene are shown in Tables 7-39 and 7-40 (see pages 7-67 and 7-68), respectively. Insufficient data for vinyl chloride prevented estimation of the carbon usage rate.

The carbon usage rate (M) in grams per liter (g/L) is calculated by the rearranged Freundlich equation:

$$\log M = \log (C_o - C_f) - \log K - \frac{1}{n} \log Cf$$

where: M = Carbon usage (g/L),
C_o = influent concentration, and
C_f = final concentration.

Using these estimates, annual carbon usage rates for each system size category for each VOC at the appropriate influent and effluent concentrations were calculated. Those systems for which the estimated carbon usage was less than 2,000 pounds per day (lb/day) were assumed to use a contractor to provide carbon regeneration/replacement services. A carbon cost of \$0.50 per pound (\$0.50/lb) (which includes handling, offsite regeneration, and transportation costs) was assumed for systems which use more than 275 pounds (lb) of carbon per day but less than 2,000 lb/day, and a carbon regeneration/replacement service cost of \$0.75/lb was assumed for those systems which have annual carbon usage of less than 275 lb/day.

Those systems for which the estimated carbon usage rate was greater than or equal to 2,000 lb/day were assumed to use multiple-hearth furnaces for onsite regeneration of the carbon. Capital costs for multiple-hearth furnaces were estimated using the general capital cost equation [from "Drinking Water Cost Equations" (EPA, 1982a)] already presented for GAC contactor capital costs. (The values of the empirical constants for this equation for multiple-hearth furnaces capital costs were 6047.0, 0.439, 1.006, 1.002, 1.0, 1.0, and 1.0 for K_2, l, m, n, o, p, and q, respectively.)

The O&M costs for multiple-hearth furnaces were developed from a general O&M equation presented in "Drinking Water Cost Equations" (EPA, 1982a) which has the form:

$$OM = K_1 \ USRT_o{}^b PR^c PPI^d DHR^e NTG^f DSL^g UN^h{}_i TDH_j MI_k G$$

where:

OM = annual O&M costs in \$/yr,

$URST_o$ = design parameter for O&M cost, area for multiple-hearth furnaces in ft^2,

PR = power cost in \$/kwhr,

PPI = Producers Price Index divided by 100,

DHR = direct hourly wage rate in dollars per hour (\$/hr),

NTG = natural gas in dollars per standard cubic feet (\$/scf), DSL = cost for diesel fuel in dollars per gallon ($/gal),

UN = number of units in a process,

TDH = total dynamic head in ft,

G = energy gradient in sec^{-1},

MI = distance in miles, and

K_1, b, c,
d, e, f,
g, h, i,
j, and k = constants estimated from regression analysis. (The values of these constants for multiple-hearth furnace O&M costs were 41,630.3, 0.809, 0.045, 1.0, 0.280, 0.581, 1.0, 1.002, 1.0, 1.0, and 1.0, respectively.)

A hearth loading rate of 40 pounds per day per square foot ($lb/day/ft^2$) was assumed to estimate hearth area. A 10-percent carbon loss per regeneration cycle and a hearth "downtime" of 40 percent were also assumed.

Estimated costs for GAC systems for several VOCs at the influent and effluent concentrations specified are shown in Tables 7-41 through 7-48 (see pages 7-69 through 7-76). There are three rows of costs for each system size in Tables 7-41 through 7-48. The top row in each size category represents total construction costs in thousands of dollars. The middle row in each size category presents O&M costs in thousands of dollars per year. The bottom row in each size category presents total production costs in cents per thousand gallons.

7.2 OTHER TREATMENT/ALTERNATIVE TECHNOLOGIES

Cost estimates and assumptions for the Other Treatment/Alternative Technologies for the removal of VOCs are presented in the following sections.

7.2.1 Multiple-Tray Aeration

Multiple-tray aeration system capital costs were developed using the capital cost equation for multiple-tray aerators described in Section 2.1 from "Drinking Water Cost Equations" (EPA, 1982a), i.e.:

$$CC = K_2 USRT_c^l \; CCI^m \; UN^n \; o^{TDH} \; p^{MI} \; q^g \qquad (1)$$

The CCI was weighted and determined particularly for multiple-tray systems using the procedure described in Section 2.1 of "Drinking Water Cost Equations" (EPA, 1982a). The weighted CCI is shown in Table 7-49 (see page 7-77). The principal design variable ($USRT_c$) for multiple-tray aeration systems is volume expressed as ft^3.

The volume of a multiple-tray aerator required was based on an aerator height of 16 ft multiplied by the required aerator area. Aerator area was based on a hydraulic loading rate of 50 gpm/ft^2. The maximum surface area of a single aerator was limited to 200 ft^2. Multiple-tray aerator dimensions for systems sizes less than 1 MGD were based on a lower hydraulic loading rate due to construction restraints. All aerators have electrically driven, induced draft fans with fan stacks and drift eliminators. The depth, surface area, and number of aerators in each system size are shown in Table 7-50 (see page 7-78).

The empirical constants used in the general cost equation for aeration towers are:

K_2 = 11.59,
l = 0.7199,
m = 0.9965, and
n, o, p, q = 1.0.

After annual costs were determined by the capital cost equation and converted to Present Worth (PW) costs, additional construction costs were added to determine the total construction costs. The additional costs include: contingencies (15 percent of the aeration system capital costs), contractor's overhead and profit (12 percent of the aeration system capital costs), and engineering fees (15 percent of the sum of the aeration system capital costs and the contractor's overhead and profit). The total construction costs and the annual cost amortized at 12 percent and 20 years are shown in Table 7-51 (see page 7-79).

Multiple-Tray Aeration Estimated O&M Costs

O&M costs were developed from a general O&M equation of the form:

$$OM = K_1 \; USRT_o^b \; PR^c \; PPI^d \; DHR^e \; NTG^f \; DSL^g \; UN \; i^{TDH} \; j^{MI} \; k^G \qquad (2)$$

where:

OM = annual O&M costs ($/yr),

$USRT_o$ = design parameter for O&M costs, i.e., volume for multiple-tray aeration (ft^3),

PR = power cost in $/kwhr,

PPI = Producers Price Index divided by 100,

DHR = direct hourly wage rate in $/hr,

NTG = natural gas in $/scf,

DSL = cost for diesel fuel in $/gal,

UN = number of units in a process,

TDH = total dynamic head in ft,

G = energy gradient in sec^{-1},

MI = distance in miles, and

k_1, b, c, d, j, k = constants estimated from regression analysis.

Specific values for various parameters for multiple-tray aeration are shown in Table 7-52 (see page 7-80), while current pricing indices and labor and energy rates are shown in Table 7-49 (see page 7-77).

Estimated O&M costs for 12 size categories are shown in Table 7-51 (see page 7-79).

7.2.2 Diffused Aeration

Costs for installing diffused aeration systems have been estimated assuming that an existing basin (such as a chlorine contact or recarbonation basin) with a detention time of 20 minutes is available which can be retrofitted with diffusers. Fine bubble diffusers were assumed to be used, with blowers providing air at an air-to-water ratio of 8:1.

Capital cost data for diffusers and blowers were obtained from another EPA contractor (Culp/Wesner/Culp) and from manufacturer's sales representatives. Air delivery piping costs are assumed to be 20 percent of the diffuser costs. Installation cost is assumed to be 50 percent of the sum of the blower, diffuser, and piping costs. Construction costs for the retrofitted diffused aeration systems for the 12 system sizes are presented in Table 7-53 (see page 7-81).

O&M costs, summarized in Table 7-53, are divided into energy, labor, and maintenance materials. Energy costs are calculated based on blower requirements of 40 hp per 1,000 cfm air. Labor and maintenance materials are calculated using the component quality (CQ) method described in "Drinking Water Cost Equations" (EPA, 1982a). The general form of the equation is:

$$CQ = A(USRT)^a$$

where: A and a = constants determined from regression analysis,
USRT = the volume in ft^3 of the aeration basin, and
CQ = hours per year for labor and dollars per year for maintenance materials.

The labor rates presented in Table 7-1 (see page 7-29) are then used to calculate annual labor costs.

7.2.3 Powdered Activated Carbon (PAC)

Costs for the use of PAC for control of VOCs have been estimated assuming that this alternative will be feasible only for conventional coagulation/filtration or softening plants which treat surface water and are already adding PAC for taste and odor control. Therefore, no capital costs were assumed to be associated with this alternative. It was also assumed that plants with a flow less than 300,000 gpd (the four smallest size categories) were likely to be package-type filtration plants without coagulation and sedimentation facilities. Therefore, this alternative was assumed to be applicable to system sizes with flow rates greater than 300,000 gpd.

An average annual PAC dose of 20 mg/L above that normally used at the plant for taste and odor control was assumed. No greater than an average of 25 to 50 percent removal of any particular VOC was expected. Existing sludge-handling facilities were assumed to be adequate for the additional PAC sludge produced. Costs are based on a PAC cost of $0.43/lb (including additional sludge disposal and labor costs), which includes a delivered PAC cost of $0.40/lb and $0.03/lb for additional sludge disposal and labor costs. Estimated costs for those plants using this alternative are shown in Table 7-54 (see page 7-82).

7.2.4 Well Field Management

The cost for a source control compliance program can vary widely. In the case of utilities which can simply take affected wells out of service, the cost is essentially zero. In the case of the Biscayne Aquifer, the cost of the program included many regulatory and administrative manhours at both the local and state level to develop effective guidelines for proper management of the aquifer resources.

Costs for a basic well field management program have been estimated and are based on the assumptions that 20 percent of the wells in a well field are contaminated and will be pumped to waste. Further, it was assumed that the system did not replace the 20-percent lost capacity.

It is assumed that a transfer pipe must be installed to route the contaminated water from the wells to a suitable discharge point. The length of the pipe is proportional to system size, that is, larger systems were assumed to require longer transfer pipes. Concrete-lined cast iron pipe was assumed to be used, sized to provide a velocity of 4 feet per second (ft/sec). The length of pipe needed was based on an assumed pipe length to diameter ratio of 2,000:1.

Estimated costs include excavation, backfilling, and thrust blocks and are based on information presented in the 1983 Dodge Guide to Public Works and Heavy Construction Costs (McMahon, 1982).

A static head of 80 feet (from water level to ground level) and the friction head for each system size category were used in calculating pumping costs. It was assumed that this alternative would be used only by systems with a capacity of approximately 1 MGD and larger. Capital, O&M, and annual costs for the appropriate system sizes for this alternative are given in Table 7-55 (see page 7-83).

7.2.5 Regionalization

The cost of regionalization is independent of the particular contaminant being considered since regionalization involves replacing the contaminated water supply with water from a (presumably larger) host community. A community may arrange for more than one host community to supply it with water; however, if multiple transmission pipelines are required, this may prove to be more expensive. Regionalization differs from alternate source development in that the basic water source has already been developed by the host community. Since regionalization is one community arranging with a neighboring community to supply it with potable water, the distance between communities was shown in this analysis to be the most sensitive factor affecting regionalization costs.

In developing the regionalization cost estimates presented here, the following assumptions were used:

1. A host community exists within reasonable distance having an adequate water supply meeting MCL requirements. Costs were developed for distances of 7.5 and 10.5 miles.
2. New facilities costs are for the pumping stations and transmission pipelines connecting the two communities.
3. The community with the water quality problem is paying a certain amount for procurement and treatment of its current water supply, and it is assumed that the neighboring community costs for procurement and water treatment will be the same. The costs of procurement and water treatment are influenced by the size of the system, quality of source water, local politics and relations between the two communities, and are so variable that consideration of the differences in these costs is not practical for this analysis.
4. Design criteria used for pumping and transmission pipeline are: pump life--30 years, pipeline life--50 years, static head--80 ft, Hazen-Williams coefficient: 140 for pipe diameters greater than or equal to 4 inches, 100 for pipe diameters less than 4 inches.
5. Cost of transmission mains may vary widely depending on the state of development in the area. It is assumed that the regionalization option will be applicable only in communities where an assumption of laying transmission mains in undeveloped areas may be valid.
6. An adequate water distribution system exists within the community with the water quality problem.
7. Estimated costs for regionalization were developed for system sizes less than 1 MGD.

Construction

Costs are subdivided into pipeline, land, and pump costs. Pipeline costs are determined by consulting the 1983 Dodge Guide to Public Works and Heavy Construction Costs (McMahon, 1983). Land costs are determined by assuming that a 25-ft easement for the entire length of transmission line is required at $500 per acre. Pump costs are obtained by referring to "Drinking Water Cost Equations" (EPA, 1982a).

O&M costs are subdivided into energy, labor, and maintenance materials. Energy costs are calculated from pump horsepower requirements and total dynamic head (TDH). Labor and maintenance materials costs are determined by referring to "Drinking Water Cost Equations" (EPA, 1982a).

Capital and operating costs for regionalization are presented in Table 7-56 (see page 7-84).

7.2.6 Bottled Water

Cost estimates for bottled water were developed based on the following assumptions:

1. The quality of the bottled water meets the MCL requirements for drinking water.
2. The bottled water will be used for drinking and cooking only.
3. Bottled water demand for drinking and cooking is based on 2 gallons per household per day with two deliveries per week per residence.
4. The source of uncontaminated water is 12.5 miles from the community where the bottled water is required.
5. Bottled water is delivered directly to the customers' door.
6. Using VOC-contaminated water for household activities, other than cooking and drinking, presents no health danger. This is unlikely since the respiratory route may be important.
7. The costs of procuring water for bottling or its pretreatment are not included since these represent only a small fraction of the cost of bottling and delivery.
8. Profits and overhead charges are not included since the water utility is responsible for the bottled water service.
9. The route distance for each size system is based upon an estimate of the existing water main distribution length.

Using the above assumptions, the costs for bottled water for the smaller communities where 100 percent of the households receive bottled water are presented in Figure 7-1 and Table 7-57 (page 7-85) (VJCA, 1984). Based on responses to a survey of bottled water distributors, averae values were used to develop capital and O&M costs for the different system size.

The total cost of bottled water was then prorated among all subscribers, which, when added to the cost of water provided by the utility, resulted in a cost per 1,000 gallons that is charged to all consumers. In this analysis, all the water consumers in a community share the cost of bottled water, not just those who receive deliveries.

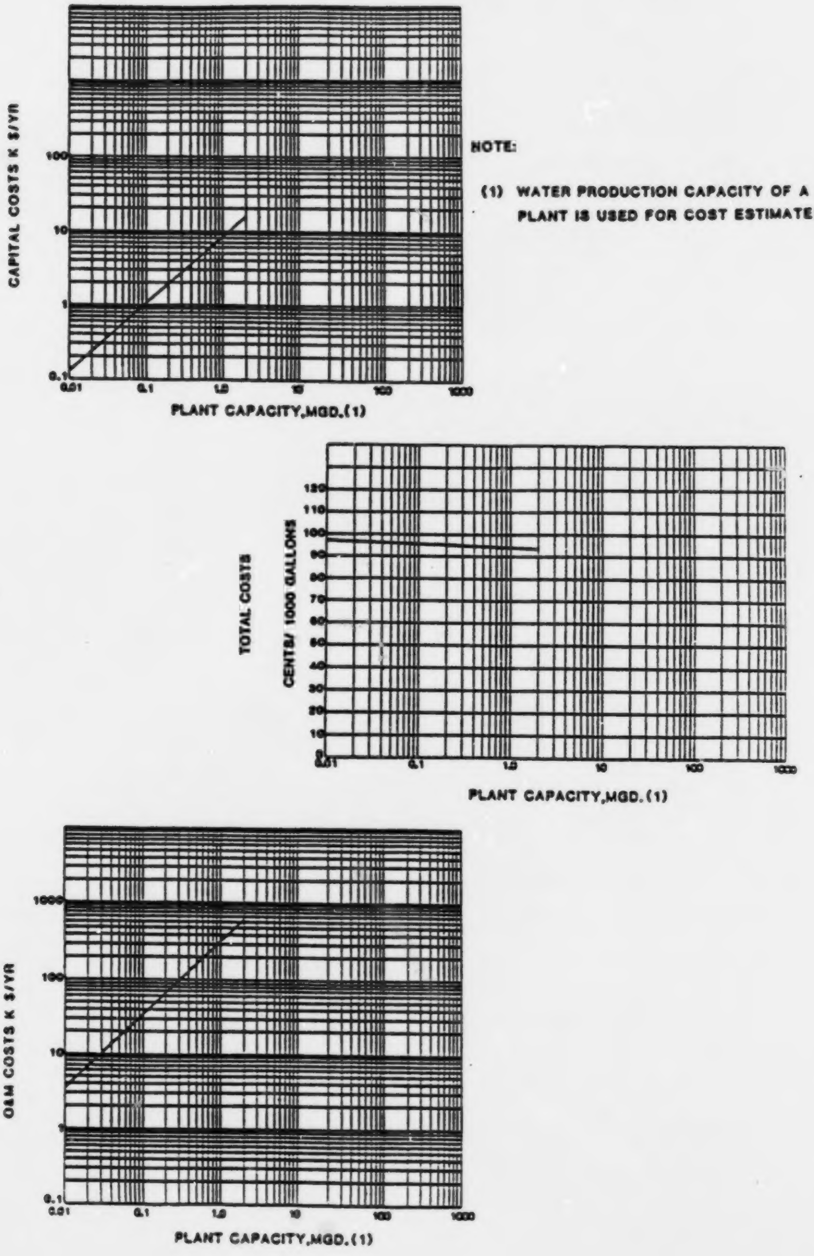
7.2.7 Alternate Source

Community water supply systems would select an alternate source if, in general, the alternate source was less expensive to develop than treatment of the existing supply for VOC removal. This is more likely to occur if only small system sizes or relatively small portions of the larger system sizes are affected by VOC contamination.

Since the majority of systems with VOC contamination which exceed the MCL obtain water from ground water supplies, costs were estimated for replacement of contaminated wells with new wells which withdraw water from uncontaminated ground water sources. Existing treatment facilities are assumed to be adequate, although the treatment process may require modification to treat the new source. Costs associated with process modifications were not developed because they are site specific.

A number of assumptions were made to develop cost estimates for alternate sources:

1. Table 7-58 (see page 7-86) presents assumptions used for estimating costs for systems currently using ground water supplies. Data obtained from a survey of community water systems (Temple, Barker, and Sloane, 1982) and a survey of the



NOTE:

(1) WATER PRODUCTION CAPACITY OF A PLANT IS USED FOR COST ESTIMATES

Figure 7-1
COSTS OF BOTTLED WATER
(100% OF THE HOUSEHOLDS)

SOURCE: EPA, 1984c.

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100 largest water systems (Durfor and Becker, 1962) were used as a basis for making many of these assumptions.

2. Table 7-59 (see page 7-87) presents assumptions used for estimating costs for alternate source development for systems using surface supplies.
3. Well specifications for estimating well construction costs are:

   Depth = 250 feet (ft), cased to 100 ft.

   Specific Capacity = 25 gallons per minute per foot (gpm/ft).

   Static Water Level = 80 ft.

   Pump Setting = 165 ft.

   It was assumed that well sites are accessible to conventional drilling rigs and an adequate water supply is available for well development. Well construction costs include testing, drilling, and development.
4. Transmission lines greater than 4 inches in diameter are cement-lined ductile iron pipe, Hazen-Williams C = 140 (American Pipe Manual, 1979). Transmission lines 4 inches and less in diameter are steel pipe, Hazen-Williams C = 100 (Viessman, 1979). Maximum velocity is less than 6 feet per second (fps). Terrain traversed by the transmission pipeline is relatively flat.
5. Transmission line construction costs include excavation, laying, thrust blocks, and backfilling.
6. Total dynamic head required to pump water to the head works of the treatment plant is 30 ft.
7. Submersible pumps are used in all wells requiring a power input of 15 horsepower (hp) or less. Vertical turbine, multi-stage pumps were selected if horsepower requirements exceed 15 hp.
8. Land requirements are 0.25 acre per well. Cost for this land is assumed to be $1,000 per acre. Wells are on 1,000-ft centers along a traverse. A 25-ft easement for the transmission line is assumed at a cost of $500 per acre.

Construction costs and operating and maintenance costs are presented in Table 7-60 (see page 7-88).

Construction costs for the transmission lines were estimated by consulting the 1983 Dodge Guide to Public Works and Heavy Construction Costs. These costs were checked and verified by comparison with actual pipeline projects for pipeline construction in nonurban areas. Costs for pipeline construction are significantly higher in urban, downtown areas due to repair of streets and relocation of other utilities.

Construction costs for well installation were estimated by obtaining estimates from well drillers in five states: New Jersey, Florida, Texas, Arizona, and Illinois. Pump costs were obtained directly from pump distributors and manufacturers' representatives.

Operating and maintenance costs are segregated into energy, maintenance materials, and labor costs. Energy costs for ground water systems were based on the flow and friction head loss due to the transmission line length only. No additional costs associated with total dynamic head are included because existing ground water systems already have energy costs pertaining to withdrawing the raw water from the well. Total dynamic head and flow were used to estimate energy costs for surface water supplies which would use ground water supplies as an alternate source. Labor and maintenance materials costs were estimated by referring to the raw water pumping section of "Drinking Water Cost Equations" (EPA, 1982a). All costs were adjusted to August 1983 dollars.

7.3 ADDITIONAL TREATMENT TECHNOLOGIES

Cost estimates and assumptions for the Additional Treatment Technologies are presented in the following sections.

7.3.1 Home Carbon Adsorption Units

Point-of-Use (Line-Bypass) Carbon Adsorption Units

When using these units as a treatment alternative, the following assumptions were made to determine the costs for treatment:

1. Only the two lowest population ranges (corresponding total daily flows of 13,000 and 37,000 gpd) would consider home treatment units.
2. Average household size is 2.5 persons total, and daily flow is 400 gpd per household.
3. The amount of water treated is 5 percent (20 gallons) of the total daily flow per household.
4. Thirty units and 100 units would be installed in the 13,000 and 37,000 gpd size categories, respectively.
5. The carbon usage rate would be 1.0 lb/1,000 gallons if benzene or 1,2-dichloroethane is present, and 0.5 lb/1,000 gallons if any other singular VOC is present.

Table 7-61 (see page 7-89) lists the approximate installed cost, carbon replacement costs, and the mass of activated carbon in five of these units. These costs were obtained from several manufacturers by telephone and written requests.

Based on these assumptions and using the average values of installation costs, replacement cartridge cost, and mass of carbon outlined in Table 7-61, the estimated capital and O&M costs are shown in Table 7-62 (see page 7-90). The carbon replacement frequency assumed for the benzene and 1,2-dichloroethane group is twice that of other compounds [based on the worst-case (500 ug/L influent concentration, 1 ug/L effluent concentration) occurrence of any particular VOC]. The assumed replacement frequency is 4 months if benzene or 1,2-dichloroethane is present and every 8 months if any other singular VOC is present. A carbon replacement frequency of 4 months was assumed for the multiple occurrence case.

Units Designed to Treat the Entire Home Water Supply (Point-of-Entry)--The following assumptions were applied to develop cost estimates for this technology:

1. Only the two lowest population ranges (corresponding total daily flows of 13,000 and 37,000 gpd) would consider point-of-entry home treatment units.
2. The average household size is 2.5 persons, and total daily flow is 400 gpd per household.
3. The amount of water treated is 75 percent (300 gallons) of the total daily flow per household. It was assumed that 25 percent of the total daily flow would be used out of the home (i.e., lawn sprinkling, car washing).
4. Thirty units and 100 units would be installed in the 13,000 and 37,000 gpd size categories, respectively.
5. The carbon usage rate would be 1.0 lb/1,000 gallons if benzene or 1,2-dichloroethane is present, and 0.5 lb/1,000 gallons if any other singular VOC is present.

The average installation costs, carbon replacement costs, and weight of carbon outlined in Table 7-63 (see page 7-91) and the aforementioned assumptions were used to estimate the capital costs and O&M costs shown in Table 7-64 (see page 7-92). The assumed carbon replacement frequency is 4 months if benzene or 1,2-dichloroethane is present and 8 months if any other singular VOC is present. For the multiple occurrence case, a carbon replacement frequency of 4 months was assumed.

7.3.2 Home Reverse Osmosis (RO) Units

Point-of-Use (Line-Bypass Units)--When using these units as a treatment alternative, the following assumptions were made to determine the costs for treatment:

1. Only the two lowest population ranges (corresponding total daily flows of 13,000 and 37,000 gpd) would consider home treatment units.
2. The average household size is 2.5 persons, and daily flow is 400 gpd per household.
3. The amount of water treated is 1 percent (4 gallons) of the total daily flow per household.
4. Thirty units and 100 units would be installed in the 13,000 and 37,000 gpd size categories, respectively.

Table 7-65 (see page 7-93) lists the approximate installed cost and replacement costs of each component of four of these units. These costs were obtained from several manufacturers by telephone communication and written requests. The replacement costs were based on a prefilter and carbon filter life of 6 to 12 months, and an RO membrane life of 2 years.

Capital and O&M costs, shown in Table 7-66 (see page 7-94), were estimated based on these assumptions and using the average values of installation costs, filter replacement cost, carbon replacement cost, and membrane replacement costs presented in Table 7-65.

Table 7-1. General Cost Assumptions for Estimating Technology Costs

Treatment	Cost
Electric power	$ 0.07 kWh
Labor	$11.00/hr for plants with flows greater than 150,000 gpd, $4.55/hr for plants with lesser flows
Diesel Fuel	$ 1.00/gal
Natural Gas	$ 0.004/scf
CCI Index, (August 1983)	385
PPI Index (August 1983)	285
Sitework	15% of construction costs
Contractor's Overhead and Profit	12% of construction costs
Contingencies	15% of construction costs
Engineering and Technical Fee	15% of the sum of the contractor's overhead and profit and construction costs
Interest Rate	12%
Number of Years	20 for structural capital construction, 5 for mechanical equipment

scf = standard cubic foot.

Table 7-2. Compounds and Assumed Henry's Constants

Compound	Assumed Henry's Constant @ 12°C atm (KM water, KM^{-1} air)
Trichloroethylene	155
Tetrachloroethylene	274
Carbon Tetrachloride	261
1,2-Dichloroethane	34
Vinyl Chloride	2,985
1,1-Dichloroethylene	498
Benzene	75
1,1,1-Trichloroethane	286
p-Dichlorobenzene	40

Source: EPA, 1984b.

Table 7-3 ESTIMATED COSTS FOR REMOVING TRICHLOROETHYLENE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	59	54	52	49	47	45	56	51	49	47	45	43	54	49	47	45	43	51	47	45	43	50	45	43	47	43	45
0.013	O&M Cost (K$/year)	0.94	0.80	0.78	0.67	0.61	0.54	0.86	0.73	0.67	0.59	0.52	0.40	0.80	0.67	0.61	0.52	0.40	0.75	0.61	0.54	0.40	0.69	0.54	0.47	0.61	0.40	0.54
	Total Production Cost (cents/1,000 gal)	188.5	169.2	162.5	152.4	145.5	138.3	181.0	159.3	152.4	143.6	137.9	130.0	169.2	152.4	145.5	137.9	130.0	159.7	145.5	138.3	130.0	155.6	138.3	131.2	145.5	130.0	138.3
101-500	Total Capital Cost (K$)	76	69	66	62	59	56	72	65	62	59	58	52	69	62	59	58	52	66	59	56	52	63	56	55	59	52	56
0.087	O&M Cost (K$/year)	1.60	1.40	1.30	1.10	0.96	0.82	1.50	1.20	1.10	0.91	0.78	0.66	1.40	1.10	0.96	0.78	0.66	1.30	0.96	0.82	0.66	1.10	0.82	0.70	0.96	0.66	0.82
	Total Production Cost (cents/1,000 gal)	87.2	79.0	75.0	70.0	66.0	62.0	82.0	73.0	70.0	64.6	60.0	56.0	79.0	70.0	66.0	60.0	56.0	75.0	66.0	62.0	56.0	71.0	62.0	58.0	66.0	56.0	62.0
501-1,000	Total Capital Cost (K$)	100	91	86	80	75	71	96	84	80	74	70	65	91	80	75	70	65	86	75	71	65	83	71	66	75	65	71
0.050	O&M Cost (K$/year)	3.2	2.6	2.4	2.0	1.7	1.5	2.9	2.3	2.0	1.7	1.4	1.2	2.6	2.0	1.7	1.4	1.2	2.4	1.7	1.5	1.2	2.1	1.5	1.2	1.7	1.2	1.5
	Total Production Cost (cents/1,000 gal)	48.9	43.6	41.0	37.4	34.6	32.4	46.4	39.9	37.4	34.2	31.7	29.2	43.6	37.4	34.6	31.7	29.2	41.0	34.6	32.4	29.2	38.1	32.4	29.6	34.6	29.2	32.4
1,001-3,300	Total Capital Cost (K$)	[illegible]	138	129	117	109	101	147	126	117	107	98	89	138	117	109	98	89	129	109	101	89	120	101	92	109	89	101
0.280	O&M Cost (K$/year)	7.5	6.2	5.6	4.8	4.1	3.5	6.8	5.5	4.8	3.9	3.3	2.7	6.2	4.8	4.1	3.3	2.7	5.6	4.1	3.5	2.7	5.0	3.5	2.9	4.1	2.7	3.5
	Total Production Cost (cents/1,000 gal)	28.2	24.1	22.4	20.1	18.3	16.6	25.9	21.9	20.1	17.8	16.1	14.2	24.1	20.1	18.3	16.1	14.2	22.4	18.3	16.6	14.2	20.6	16.6	14.9	18.3	14.2	16.6
3,301-10,000	Total Capital Cost (K$)	314	264	243	216	197	178	286	243	216	191	171	149	264	216	197	171	149	243	197	178	149	222	178	158	197	149	178
0.982	O&M Cost (K$/year)	22	18	17	14	12	11	20	17	14	12	10	8	18	14	12	10	8	17	12	11	8	15	11	9	12	8	11
	Total Production Cost (cents/1,000 gal)	18.3	15.5	14.2	12.5	11.1	9.9	16.8	14.2	12.5	10.7	9.4	8.1	15.5	12.5	11.1	9.4	8.1	14.2	11.1	9.9	8.1	12.9	9.9	8.6	11.1	8.1	9.9
10,001-25,000	Total Capital Cost (K$)	621	529	480	434	393	351	569	475	434	379	337	276	529	434	393	337	276	480	393	351	276	440	351	294	393	276	351
2.753	O&M Cost (K$/year)	62	50	44	39	33	28	55	43	39	32	27	23	50	39	33	27	23	44	33	28	23	39	28	24	33	23	28
	Total Production Cost (cents/1,000 gal)	14.4	12.0	10.9	9.5	8.5	7.5	13.0	10.6	9.5	8.2	7.2	5.9	12.0	9.5	8.5	7.2	5.9	10.9	8.5	7.5	5.9	9.9	7.5	6.3	8.5	5.9	7.5
25,001-50,000	Total Capital Cost (K$)	1,240	1,047	966	850	774	690	1,127	940	850	747	663	540	529	434	393	337	276	480	393	351	276	440	351	294	393	276	351
6.060	O&M Cost (K$/year)	135	110	98	83	73	63	121	94	83	69	59	50	50	39	33	27	23	44	33	28	23	39	28	24	33	23	28
	Total Production Cost (cents/1,000 gal)	13.6	11.3	10.3	8.9	8.0	7.0	12.3	9.9	8.9	7.6	6.7	5.5	5.4	4.5	3.9	3.3	2.7	5.0	3.9	3.4	2.7	4.5	3.4	2.9	3.9	2.7	3.4
50,001-75,000	Total Capital Cost (K$)	2,153	1,783	1,643	1,460	1,318	1,174	1,931	1,600	1,460	1,272	1,127	919	1,783	1,460	1,318	1,127	919	1,643	1,318	1,174	919	1,500	1,174	982	1,318	919	1,174
11.680	O&M Cost (K$/year)	247	204	182	155	135	116	224	175	155	129	110	92	204	155	135	110	92	182	135	116	92	161	116	97	135	92	116
	Total Production Cost (cents/1,000 gal)	12.6	10.4	9.4	8.2	7.3	6.4	11.3	9.1	8.2	7.0	6.1	5.0	10.4	8.2	7.3	6.1	5.0	9.4	7.3	6.4	5.0	8.5	6.4	5.4	7.3	5.0	6.4
75,000-100,000	Total Capital Cost (K$)	2,751	2,253	2,079	1,845	1,667	1,485	2,467	2,022	1,845	1,608	1,426	1,166	2,253	1,845	1,667	1,426	1,166	2,079	1,667	1,485	1,166	1,905	1,485	1,246	1,667	1,166	1,485
15.912	O&M Cost (K$/year)	331	276	247	209	182	156	300	237	209	174	149	124	276	209	182	149	124	247	182	156	124	218	156	131	182	124	156
	Total Production Cost (cents/1,000 gal)	12.0	9.9	9.0	7.9	7.0	6.1	10.9	8.7	7.9	6.7	5.8	4.8	9.9	7.9	7.0	5.8	4.8	9.0	7.0	6.1	4.8	8.1	6.1	5.1	7.0	4.8	6.1
100,001-500,000	Total Capital Cost (K$)	5,804	4,789	4,378	3,796	3,014	3,130	5,251	4,260	3,852	3,396	3,014	2,475	4,789	3,852	3,510	3,014	2,475	4,378	3,510	3,130	2,475	4,011	3,130	2,642	3,510	2,475	3,130
36.006	O&M Cost (K$/year)	737	617	557	391	335	352	669	536	472	391	335	279	617	472	410	335	279	557	410	352	279	492	352	295	410	279	352
	Total Production Cost (cents/1,000 gal)	11.3	9.4	8.5	6.5	5.5	5.7	10.2	8.2	7.4	6.3	5.5	4.5	9.4	7.4	6.6	5.5	4.5	8.5	6.6	5.7	4.5	7.7	5.7	4.8	6.6	4.5	5.7
500,001-1,000,000	Total Capital Cost (K$)	19,419	15,898	14,386	12,807	11,394	10,359	17,425	14,004	12,807	11,198	9,959	8,216	15,898	12,807	11,394	9,959	8,217	14,386	11,394	10,359	8,217	13,194	10,359	8,759	11,394	8,217	10,359
129.421	O&M Cost (K$/year)	2,561	2,148	1,962	1,660	1,443	1,238	2,327	1,887	1,660	1,376	1,175	981	2,148	1,660	1,443	1,175	981	1,962	1,443	1,238	981	1,732	1,238	1,038	1,443	981	1,238
	Total Production Cost (cents/1,000 gal)	10.9	9.1	8.2	7.1	6.3	5.6	9.9	8.0	7.1	6.1	5.3	4.4	9.1	7.1	6.3	5.3	4.4	8.2	6.3	5.7	4.4	7.4	5.6	4.7	6.3	4.4	5.6
>1,000,000	Total Capital Cost (K$)	73,188	59,983	54,177	47,918	43,477	38,896	63,708	52,238	47,918	41,991	37,418	31,034	59,983	47,918	43,477	37,418	31,034	54,177	43,447	38,896	31,034	49,344	38,896	33,027	43,447	31,034	38,896
517.491	O&M Cost (K$/year)	10,097	8,486	7,774	6,626	5,756	4,936	9,186	7,595	6,626	5,486	4,684	3,912	8,486	6,626	5,756	4,684	3,912	7,774	5,756	4,936	3,912	6,915	4,936	4,140	5,756	3,912	4,936
	Total Production Cost (cents/1,000 gal)	10.5	8.7	8.0	6.9	6.1	5.4	9.5	7.7	6.9	5.9	5.1	4.3	8.7	6.9	6.1	5.1	4.3	8.0	6.1	5.4	4.3	7.2	5.4	4.5	6.1	4.3	5.4

MGD= million gallons per day

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Table 7-4 ESTIMATED COSTS FOR REMOVING TETRACHLOROETHYLENE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																													
		500 (ug/L)							200 (ug/L)							100 (ug/L)						50 (ug/L)					25 (ug/l)				10
		Effluent (ug/L)							Effluent (ug/L)							Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Efflue
		1	5	10	15	25	50	100	1	5	10	15	25	50	100	1	5	10	15	25	50	1	5	10	15	25	1	5	10	15	1
25-100 0.015	Total Capital Cost (K$)	57	53	51	50	48	47	45	54	50	48	47	46	44	43	53	48	47	46	44	43	51	47	45	44	43	49	45	43	42	47
	O&M Cost (K$/year)	0.9	0.7	0.7	0.7	0.6	0.6	0.5	0.8	0.7	0.6	0.6	0.5	0.5	0.4	0.7	0.6	0.6	0.5	0.5	0.4	0.7	0.6	0.5	0.5	0.4	0.6	0.5	0.5	0.4	0.6
	Total Production Cost (cents/1,000 gal)	179.2	163.2	158.1	155.0	149.2	144.1	137.2	170.5	156.4	149.2	146.1	140.6	134.5	128.5	163.2	149.2	144.1	139.2	134.5	128.5	158.1	144.1	137.2	134.7	128.5	150.9	137.2	132.1	126.9	144.1
101-500 0.037	Total Capital Cost (K$)	73	67	64	63	61	58	56	70	64	61	59	57	55	52	67	61	58	57	55	52	64	58	56	54	51	62	56	53	51	58
	O&M Cost (K$/year)	1.5	1.2	1.1	1.0	1.0	0.9	0.8	1.3	1.1	1.0	0.9	0.8	0.7	0.6	1.2	1.0	0.9	0.8	0.7	0.6	1.1	0.9	0.8	0.7	0.6	1.0	0.8	0.7	0.6	0.9
	Total Production Cost (cents/1,000 gal)	83.6	75.0	72.0	70.0	68.0	64.0	61.0	79.0	71.0	68.0	65.0	63.0	60.0	55.0	75.0	68.0	64.0	62.0	60.0	55.0	72.0	64.0	61.0	59.0	55.0	69.0	61.0	57.0	55.0	64.0
501-1,000 0.093	Total Capital Cost (K$)	90	89	85	82	79	75	71	93	83	79	77	73	69	64	89	79	75	72	69	64	85	75	71	67	64	80	71	65	63	75
	O&M Cost (K$/year)	2.7	2.2	2.0	1.9	1.7	1.6	1.4	2.4	1.9	1.7	1.6	1.5	1.3	1.1	2.2	1.7	1.6	1.5	1.3	1.1	2.0	1.6	1.4	1.3	1.1	1.8	1.4	1.2	1.1	1.6
	Total Production Cost (cents/1,000 gal)	46.6	41.4	39.2	37.9	36.2	34.2	32.0	43.6	38.4	36.2	34.9	33.4	31.0	28.4	41.4	36.2	34.2	32.9	31.0	28.4	39.2	34.2	32.0	30.4	28.4	37.0	32.0	29.3	27.9	34.2
1,001-3,300 0.288	Total Capital Cost (K$)	152	134	126	122	116	108	100	142	124	116	111	105	96	87	134	116	108	103	96	87	126	108	100	94	87	118	100	90	85	108
	O&M Cost (K$/year)	6.2	5.2	4.7	4.4	4.1	3.7	3.2	5.6	4.6	4.1	3.8	3.5	3.1	2.7	5.2	4.1	3.7	3.4	3.1	2.7	4.7	3.7	3.2	3.0	2.7	4.2	3.2	2.8	2.6	3.7
	Total Production Cost (cents/1,000 gal)	25.9	22.6	21.1	20.2	19.2	17.8	16.2	24.0	20.7	19.2	18.3	17.2	15.6	14.0	22.6	19.2	17.8	16.9	15.6	14.0	21.1	17.8	16.2	15.2	14.0	19.6	16.2	14.5	13.6	17.8
3,301-10,000 0.952	Total Capital Cost (K$)	295	252	238	225	211	194	174	270	229	211	201	188	170	146	252	211	194	183	170	146	238	194	174	161	146	217	174	152	140	194
	O&M Cost (K$/year)	19	15	14	13	12	11	10	17	14	12	12	11	9	8	15	12	11	10	9	8	14	11	10	9	8	13	10	8	8	11
	Total Production Cost (cents/1,000 gal)	16.6	14.2	13.1	12.5	11.7	10.6	9.5	15.2	12.7	11.7	11.0	10.3	9.2	7.9	14.2	11.7	10.6	10.0	9.2	7.9	13.1	10.6	9.5	8.8	7.9	12.0	9.5	8.3	7.7	10.6
10,001-25,000 2.753	Total Capital Cost (K$)	606	517	479	457	437	376	327	556	467	427	397	360	310	260	517	427	376	347	310	260	479	376	327	300	260	441	327	282	250	376
	O&M Cost (K$/year)	49	41	38	36	33	30	26	45	37	33	31	29	25	22	41	33	30	28	25	32	38	30	26	24	22	35	26	23	21	30
	Total Production Cost (cents/1,000 gal)	13.0	11.0	10.2	9.7	9.0	8.0	7.0	11.9	9.9	9.0	8.4	7.6	6.6	5.8	11.0	9.0	8.0	7.4	6.6	5.8	10.2	8.0	7.0	6.4	5.8	9.3	7.0	6.0	5.5	8.0
25,001-50,000 6.065	Total Capital Cost (K$)	1,198	1,022	946	901	844	742	643	1,098	921	844	784	710	610	525	1,022	844	742	684	610	525	946	742	643	589	525	869	643	552	504	742
	O&M Cost (K$/year)	109	91	85	79	74	65	58	99	81	74	69	63	55	48	91	74	65	61	55	48	83	65	58	53	48	76	58	50	47	65
	Total Production Cost (cents/1,000 gal)	12.2	10.5	9.5	9.0	8.4	7.4	6.5	11.1	9.2	8.4	7.8	7.1	6.2	5.3	10.3	8.4	7.4	6.9	6.2	5.4	9.5	7.4	6.5	6.0	5.4	8.7	6.5	5.6	5.2	7.4
50,001-75,000 11.680	Total Capital Cost (K$)	2,037	1,737	1,607	1,531	1,434	1,263	1,095	1,867	1,560	1,434	1,335	1,208	1,000	894	1,737	1,434	1,263	1,164	1,000	894	1,607	1,263	1,096	1,002	894	1,477	1,095	940	857	1,263
	O&M Cost (K$/year)	201	169	154	146	136	121	107	183	150	136	127	116	100	90	169	136	121	113	100	90	154	121	107	99	90	141	107	94	87	121
	Total Production Cost (cents/1,000 gal)	11.1	9.4	8.7	8.2	7.7	6.8	5.9	10.1	8.4	7.7	7.2	6.5	5.5	4.9	9.4	7.7	6.8	6.3	5.5	4.9	8.7	6.8	5.9	5.5	4.9	7.9	5.9	5.1	4.7	6.8
75,000-100,000 15.912	Total Capital Cost (K$)	2,560	2,192	2,028	1,932	1,811	1,600	1,380	2,354	1,975	1,811	1,690	1,550	1,380	1,134	2,192	1,811	1,600	1,475	1,380	1,134	2,028	1,600	1,380	1,271	1,134	1,864	1,380	1,192	1,088	1,600
	O&M Cost (K$/year)	272	228	209	198	184	164	144	247	202	184	172	157	140	121	228	·184	164	152	140	121	209	164	144	133	121	190	144	126	117	164
	Total Production Cost (cents/1,000 gal)	10.6	9.0	8.3	7.9	7.3	6.5	5.7	9.7	8.0	7.3	6.9	6.2	5.4	4.7	9.0	7.3	6.5	6.0	5.4	4.7	8.3	6.5	5.7	5.2	4.7	7.6	5.7	4.9	4.5	6.5
100,001-500,000 36.806	Total Capital Cost (K$)	5,352	4,607	4,266	4,065	3,813	3,381	2,939	4,946	4,156	3,813	3,570	3,236	2,880	2,408	4,607	3,813	3,381	3,119	2,880	2,408	4,266	3,381	2,939	2,695	2,408	3,925	2,939	2,530	2,313	3,381
	O&M Cost (K$/year)	614	513	469	444	413	368	325	556	456	413	387	354	310	273	513	413	368	342	310	273	469	368	325	301	273	427	325	285	263	368
	Total Production Cost (cents/1,000 gal)	9.9	8.4	7.7	7.4	6.9	6.1	5.3	9.1	7.5	6.9	6.4	5.9	5.1	4.4	8.4	6.9	6.1	5.7	5.1	4.4	7.7	6.1	5.3	4.9	4.4	7.1	5.3	4.6	4.3	[illegible]
500,001-1,000,000 129.421	Total Capital Cost (K$)	17,639	15,098	13,998	13,346	12,527	11,153	9,722	16,196	13,638	12,527	11,766	10,640	9,300	8,001	15,098	12,527	11,153	10,307	9,300	8,001	13,995	11,153	9,722	8,930	8,001	12,880	9,722	8,396	7,693	11,153
	O&M Cost (K$/year)	2,158	1,801	1,649	1,561	1,451	1,294	1,141	1,984	1,600	1,451	1,360	1,244	1,100	999	1,801	1,451	1,294	1,205	1,100	999	1,649	1,294	1,141	1,057	999	1,499	1,141	1,000	926	1,294
	Total Production Cost (cents/1,000 gal)	9.6	8.1	7.5	7.1	6.6	5.9	5.2	8.7	7.3	6.6	6.2	5.7	5.0	4.5	8.1	6.6	5.9	5.5	5.0	4.3	7.5	5.9	5.2	4.8	4.3	6.8	5.2	4.5	4.1	5.9
>1,000,000 317.491	Total Capital Cost (K$)	65,597	56,298	52,201	49,817	46,804	41,840	36,572	60,293	50,891	46,804	44,096	40,114	35,000	30,239	56,298	46,804	41,840	38,723	35,000	30,239	52,201	41,840	36,572	33,626	30,239	48,121	36,572	31,691	29,106	41,840
	O&M Cost (K$/year)	8,609	7,180	6,572	6,219	5,770	5,158	4,548	7,793	6,377	5,770	5,420	4,938	4,400	3,823	7,180	5,770	5,158	4,756	4,400	3,823	6,572	5,158	4,548	4,213	3,823	5,970	4,546	3,988	3,698	5,158
	Total Production Cost (cents/1,000 gal)	9.2	7.8	7.2	6.8	6.4	5.7	5.0	8.4	7.0	6.4	6.0	5.5	4.8	4.2	7.8	6.4	5.7	5.3	4.8	4.2	7.2	5.7	5.0	4.6	4.2	6.6	5.0	4.4	4.0	5.7

MGD= million gallons per day

Table 7-5 ESTIMATED COSTS FOR REMOVING CARBON TETRACHLORIDE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	56	52	51	48	46	45	54	50	48	46	44	42	52	48	46	44	42	51	46	45	42	49	45	43	46	42	45
0.013	O&M Cost (K$/year)	0.8	0.7	0.7	0.6	0.6	0.5	0.8	0.7	0.6	0.5	0.5	0.4	0.7	0.6	0.6	0.5	0.4	0.7	0.6	0.5	0.4	0.6	0.5	0.5	0.6	0.4	0.5
	Total Production Cost (cents/1,000 gal)	175.7	162.3	157.2	148.6	143.6	136.9	169.2	150.8	148.6	140.0	133.5	128.1	162.3	148.6	143.6	133.5	128.1	157.2	143.6	136.9	128.1	150.5	136.9	131.9	143.6	128.1	136.9
101-500	Total Capital Cost (K$)	73	66	64	61	58	55	69	63	61	57	55	51	66	61	58	55	51	64	58	55	51	61	55	52	58	51	55
0.037	O&M Cost (K$/year)	1.4	1.2	1.1	1.0	0.9	0.8	1.3	1.1	1.0	0.8	0.7	0.6	1.2	1.0	0.9	0.7	0.6	1.1	0.9	0.8	0.6	1.0	0.8	0.7	0.9	0.6	0.8
	Total Production Cost (cents/1,000 gal)	82.2	75.0	71.0	67.0	64.0	61.0	78.0	71.0	67.0	63.0	59.0	55.0	75.0	67.0	64.0	59.0	55.0	71.0	64.0	61.0	55.0	68.0	61.0	57.0	64.0	55.0	61.0
501-1,000	Total Capital Cost (K$)	97	88	84	78	74	70	92	82	78	73	69	64	88	78	74	69	64	84	74	70	64	80	70	65	74	64	70
0.093	O&M Cost (K$/year)	2.7	2.2	2.0	1.7	1.6	1.4	2.4	1.9	1.7	1.5	1.3	1.1	2.2	1.7	1.6	1.3	1.1	2.0	1.6	1.4	1.1	1.8	1.4	1.2	1.6	1.1	1.4
	Total Production Cost (cents/1,000 gal)	46.2	41.1	38.9	35.9	34.0	31.8	43.2	38.1	35.9	33.2	30.9	28.3	41.1	35.9	34.0	30.9	28.3	38.9	34.0	31.8	28.3	36.7	31.8	29.2	34.0	28.3	31.8
1,001-3,300	Total Capital Cost (K$)	149	132	125	115	107	99	140	122	115	105	96	87	132	115	107	96	87	125	107	99	87	117	99	90	107	87	99
0.280	O&M Cost (K$/year)	6.2	5.1	4.7	4.1	3.6	3.2	5.6	4.5	4.1	3.5	3.1	2.7	5.1	4.1	3.6	3.1	2.7	4.7	3.6	3.2	2.7	4.2	3.2	2.8	3.6	2.7	3.2
	Total Production Cost (cents/1,000 gal)	25.6	22.3	20.9	19.0	17.6	16.1	23.8	20.4	19.0	17.1	15.6	14.0	22.3	19.0	17.6	15.6	14.0	20.9	17.6	16.1	14.0	19.5	16.1	14.8	17.6	14.0	16.1
3,301-10,000	Total Capital Cost (K$)	288	249	232	209	192	173	266	226	209	186	166	145	249	209	192	166	145	232	192	173	145	215	173	151	192	145	173
0.902	O&M Cost (K$/year)	19	16	14	12	11	10	17	14	12	11	9	8	16	12	11	9	8	14	11	10	8	13	10	8	11	8	10
	Total Production Cost (cents/1,000 gal)	16.4	14.0	13.0	11.6	10.5	9.4	15.0	12.6	11.6	10.2	9.0	7.9	14.0	11.6	10.5	9.0	7.9	13.0	10.5	9.4	7.9	11.9	9.4	8.2	10.5	7.9	9.4
10,001-20,000	Total Capital Cost (K$)	590	509	472	423	373	325	546	460	423	357	310	267	509	423	373	310	267	472	373	325	267	433	325	280	373	267	325
2.753	O&M Cost (K$/year)	49	41	38	33	30	26	44	37	33	28	25	22	41	33	30	25	22	38	30	26	22	34	26	23	30	22	26
	Total Production Cost (cents/1,000 gal)	12.8	10.9	10.0	8.9	7.9	6.9	11.7	9.8	8.9	7.6	6.6	5.7	10.9	8.9	7.9	6.6	5.7	10.0	7.9	6.9	5.7	9.2	6.9	6.0	7.9	5.7	6.9
25,001-50,000	Total Capital Cost (K$)	1,177	1,006	931	833	735	639	1,080	908	833	703	609	523	1,006	833	735	609	523	931	735	639	523	857	639	580	735	523	639
6.060	O&M Cost (K$/year)	108	90	83	73	65	57	98	80	73	63	55	48	90	73	65	55	48	83	65	57	48	75	57	50	65	48	57
	Total Production Cost (cents/1,000 gal)	12.0	10.2	9.4	8.3	7.4	6.5	10.9	9.1	8.3	7.1	6.2	5.3	10.2	8.3	7.4	6.2	5.3	9.4	7.4	6.5	5.3	8.6	6.5	5.6	7.4	5.3	6.5
50,001-75,000	Total Capital Cost (K$)	2,001	1,710	1,583	1,415	1,251	1,087	1,836	1,543	1,415	1,198	1,037	890	1,710	1,415	1,251	1,037	890	1,583	1,251	1,087	890	1,456	1,087	933	1,251	890	1,087
11.680	O&M Cost (K$/year)	200	167	153	135	121	106	181	149	135	116	102	90	167	135	121	102	90	153	121	106	90	140	106	93	121	90	106
	Total Production Cost (cents/1,000 gal)	11.0	9.3	8.6	7.6	6.8	5.9	10.0	8.3	7.6	6.5	5.6	4.9	9.3	7.6	6.8	5.6	4.9	8.6	6.8	5.9	4.9	7.8	5.9	5.1	6.8	4.9	5.9
75,000-100,000	Total Capital Cost (K$)	2,523	2,157	1,998	1,787	1,580	1,378	2,316	1,947	1,787	1,517	1,314	1,130	2,157	1,787	1,580	1,314	1,130	1,998	1,580	1,378	1,130	1,839	1,378	1,187	1,580	1,130	1,378
18.912	O&M Cost (K$/year)	270	226	207	182	163	144	248	201	182	156	138	121	226	182	163	138	121	207	163	144	121	188	144	126	163	121	144
	Total Production Cost (cents/1,000 gal)	10.5	8.9	8.2	7.3	6.5	5.6	9.6	7.9	7.3	6.2	5.4	4.7	8.9	7.3	6.5	5.4	4.7	8.2	6.5	5.6	4.7	7.5	5.6	4.9	6.5	4.7	5.6
100,001-500,000	Total Capital Cost (K$)	5,299	4,537	4,205	3,763	3,350	2,918	4,866	4,098	3,763	3,208	2,785	2,399	4,537	3,763	3,350	2,785	2,399	4,205	3,350	2,918	2,399	3,871	2,918	2,518	3,350	2,399	2,918
36.085	O&M Cost (K$/year)	609	509	466	410	366	323	552	452	410	352	310	272	509	410	366	310	272	466	366	323	272	424	323	284	366	272	323
	Total Production Cost (cents/1,000 gal)	9.8	8.3	7.7	6.8	6.1	5.3	9.0	7.5	6.8	5.8	5.1	4.4	8.3	6.8	6.1	5.1	4.4	7.7	6.1	5.3	4.4	7.0	5.3	4.6	6.1	4.4	5.3
500,001-1,000,000	Total Capital Cost (K$)	17,342	14,873	13,800	12,371	11,054	9,653	15,940	13,453	12,371	10,594	9,221	7,974	14,873	12,371	11,054	9,221	7,974	13,800	11,054	9,653	7,974	12,720	9,653	8,358	11,054	7,974	9,653
129.421	O&M Cost (K$/year)	2,141	1,788	1,637	1,441	1,287	1,137	1,939	1,589	1,441	1,238	1,090	958	1,788	1,441	1,287	1,090	958	1,637	1,287	1,137	958	1,488	1,137	999	1,287	958	1,137
	Total Production Cost (cents/1,000 gal)	9.4	8.0	7.4	6.6	5.9	5.1	8.6	7.2	6.6	5.6	4.9	4.3	8.0	6.6	5.9	4.9	4.3	7.4	5.9	5.1	4.3	6.8	5.1	4.3	5.9	4.3	5.1
>1,000,000	Total Capital Cost (K$)	64,517	55,443	51,497	46,242	41,474	36,317	59,364	50,221	46,242	39,784	34,730	30,140	55,443	46,242	41,474	34,730	30,140	51,497	41,474	36,317	30,140	47,525	36,317	31,553	41,474	30,140	36,317
517.491	O&M Cost (K$/year)	8,844	7,128	6,525	5,739	5,130	4,531	7,738	6,332	5,739	4,933	4,347	3,820	7,128	5,739	5,130	4,347	3,820	6,525	5,130	4,531	3,820	5,929	4,531	3,982	5,130	3,820	4,531
	Total Production Cost (cents/1,000 gal)	9.1	7.7	7.1	6.3	5.7	5.0	8.3	6.9	6.3	5.4	4.8	4.2	7.7	6.3	5.7	4.8	4.2	7.1	5.7	5.0	4.2	6.5	5.0	4.3	5.7	4.2	5.0

MGD= million gallons per day

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Table 7-6 ESTIMATED COSTS FOR REMOVING 1,2-DICHLOROETHANE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	69	62	59	56	52	49	65	58	56	51	48	44	62	56	52	48	44	59	52	49	44	56	49	45	52	44	49
0.013	O&M Cost (K$/year)	1.6	1.3	1.2	1.0	0.9	0.7	1.4	1.1	1.0	0.8	0.7	0.6	1.3	1.0	0.9	0.7	0.6	1.2	0.9	0.7	0.6	1.1	0.7	0.6	0.9	0.6	0.7
	Total Production Cost (cents/1,000 gal)	227.0	201.5	190.9	175.7	164.8	151.6	212.1	186.3	175.7	159.9	148.8	137.4	201.5	175.7	164.8	148.8	137.4	190.9	164.8	151.6	137.4	180.3	151.6	140.5	164.8	137.4	151.6
101-500	Total Capital Cost (K$)	96	84	79	72	67	62	89	78	72	65	60	54	84	72	67	60	54	79	67	62	54	74	62	56	67	54	62
0.037	O&M Cost (K$/year)	3.0	2.4	2.2	1.8	1.6	1.3	2.7	2.1	1.8	1.5	1.2	0.9	2.4	1.8	1.6	1.2	0.9	2.2	1.6	1.3	0.9	1.9	1.3	1.0	1.6	0.9	1.3
	Total Production Cost (cents/1,000 gal)	117.4	101.0	95.0	85.0	78.0	71.0	109.0	92.0	85.0	76.0	68.0	60.0	101.0	85.0	78.0	68.0	60.0	95.0	78.0	71.0	60.0	87.0	71.0	63.0	78.0	60.0	71.0
501-1,000	Total Capital Cost (K$)	141	121	112	100	91	81	130	109	100	85	78	68	121	100	91	78	68	112	91	81	68	103	81	72	91	68	81
0.093	O&M Cost (K$/year)	6.0	4.8	4.3	3.6	3.0	2.5	5.3	4.1	3.6	2.9	2.3	1.6	4.8	3.6	3.0	2.3	1.6	4.3	3.0	2.5	1.6	3.8	2.5	1.8	3.0	1.6	2.5
	Total Production Cost (cents/1,000 gal)	75.3	61.7	56.7	49.9	44.5	39.4	66.7	54.9	49.9	43.1	37.5	31.7	61.7	49.9	44.5	37.5	31.7	56.7	44.5	39.4	31.7	51.7	39.4	33.3	44.5	31.7	39.4
1,001-3,300	Total Capital Cost (K$)	248	205	186	161	142	122	223	180	161	136	116	96	205	161	142	116	96	186	142	122	96	167	122	103	142	96	122
0.280	O&M Cost (K$/year)	14.3	11.5	10.3	8.6	7.3	5.9	12.7	9.9	8.6	6.8	5.4	3.9	11.5	8.6	7.3	5.4	3.9	10.3	7.3	5.9	3.9	9.0	5.9	4.4	7.3	3.9	5.9
	Total Production Cost (cents/1,000 gal)	46.8	38.1	34.5	29.5	25.7	21.8	41.7	33.5	29.5	24.4	20.5	16.4	38.1	29.5	25.7	20.5	16.4	34.5	25.7	21.8	16.4	30.7	21.8	17.8	25.7	16.4	21.8
3,301-10,000	Total Capital Cost (K$)	570	461	409	340	288	240	512	393	340	267	222	170	461	340	288	222	170	409	288	240	170	357	280	187	288	170	240
0.902	O&M Cost (K$/year)	47	37	33	28	23	18	41	32	28	22	16	12	37	28	23	16	12	33	23	18	12	29	23	13	23	12	18
	Total Production Cost (cents/1,000 gal)	35.6	28.5	25.4	21.1	17.7	14.3	31.6	24.3	21.1	16.6	13.2	9.9	28.5	21.1	17.7	13.2	9.9	25.4	17.7	14.3	9.9	22.1	17.7	11.0	17.7	9.9	14.3
10,001-25,000	Total Capital Cost (K$)	1,343	1,060	942	776	645	510	1,186	902	776	682	468	323	1,060	776	645	468	323	942	645	510	323	817	510	388	645	323	510
2.753	O&M Cost (K$/year)	123	99	88	74	63	51	109	85	74	59	46	33	99	74	63	46	33	88	63	51	33	70	51	38	63	33	51
	Total Production Cost (cents/1,000 gal)	30.1	24.0	21.3	17.7	14.0	11.8	26.7	20.5	17.7	13.9	10.8	7.6	24.0	17.7	14.0	10.8	7.6	21.3	14.0	11.8	7.6	18.6	11.8	8.6	14.0	7.6	11.8
25,001-50,000	Total Capital Cost (K$)	2,730	2,163	1,911	1,570	1,302	1,025	2,411	1,829	1,570	1,214	933	636	2,163	1,570	1,302	933	636	1,911	1,302	1,025	636	1,634	1,025	736	1,302	636	1,025
6.065	O&M Cost (K$/year)	264	214	191	160	136	110	236	184	160	128	101	72	214	160	136	101	72	191	136	110	72	168	110	82	136	72	110
	Total Production Cost (cents/1,000 gal)	28.5	22.7	20.2	16.7	14.0	11.2	25.2	19.4	16.7	13.1	10.2	7.1	22.7	16.7	14.0	10.2	7.1	20.2	14.0	11.2	7.1	17.6	11.2	8.1	14.0	7.1	11.2
50,001-75,000	Total Capital Cost (K$)	4,748	3,752	3,313	2,718	2,252	1,769	4,184	3,170	2,710	2,099	1,609	1,092	3,752	2,718	2,252	1,609	1,092	3,313	2,252	1,769	1,092	2,865	1,769	1,262	2,252	1,092	1,769
11.680	O&M Cost (K$/year)	480	389	349	293	249	202	429	335	293	234	186	133	389	293	249	186	133	349	249	202	133	307	202	151	249	133	202
	Total Production Cost (cents/1,000 gal)	26.2	20.9	18.6	15.4	12.9	10.3	23.2	17.8	15.4	12.1	9.4	6.6	20.9	15.4	12.9	9.4	6.6	18.6	12.9	10.3	6.6	16.2	10.3	7.5	12.9	6.6	10.3
75,000-100,000	Total Capital Cost (K$)	6,076	4,800	4,237	3,475	2,879	2,260	5,354	4,054	3,475	2,682	2,058	1,394	4,800	3,475	2,879	2,058	1,394	4,237	2,879	2,260	1,394	3,663	2,260	1,611	2,879	1,394	2,260
15.912	O&M Cost (K$/year)	638	518	464	391	332	270	571	447	391	313	249	179	518	391	332	249	179	464	332	270	179	409	270	202	332	179	270
	Total Production Cost (cents/1,000 gal)	25.0	20.0	17.8	14.7	12.4	9.9	22.2	17.0	14.7	11.6	9.0	6.3	20.0	14.7	12.4	9.0	6.3	17.8	12.4	9.9	6.3	15.5	9.9	7.2	12.4	6.3	9.9
100,001-500,000	Total Capital Cost (K$)	12,932	10,221	9,024	7,402	6,134	4,817	11,399	8,633	7,402	5,716	4,380	2,975	10,221	7,402	6,134	4,380	2,975	9,024	6,134	4,817	2,975	7,802	4,817	3,437	6,134	2,975	4,817
36.006	O&M Cost (K$/year)	1,414	1,149	1,031	869	740	602	1,264	992	869	697	556	402	1,149	869	740	556	402	1,031	740	602	402	909	602	453	740	402	602
	Total Production Cost (cents/1,000 gal)	23.4	18.7	16.7	13.8	11.6	9.3	20.8	16.0	13.8	10.9	8.5	6.0	18.7	13.8	11.6	8.5	6.0	16.7	11.6	9.3	6.0	14.5	9.3	6.8	11.6	6.0	9.3
500,001-1,000,000	Total Capital Cost (K$)	42,080	33,916	29,956	24,587	20,388	16,027	37,815	28,664	24,587	19,004	14,580	9,919	33,916	24,587	20,388	14,580	9,919	29,956	20,388	16,027	9,919	25,911	16,027	11,451	20,388	9,919	16,027
129.421	O&M Cost (K$/year)	4,678	3,972	3,568	3,013	2,571	2,098	4,366	3,436	3,013	2,422	1,938	1,405	3,972	3,013	2,571	1,938	1,405	3,568	2,571	2,098	1,405	3,151	2,098	1,585	2,571	1,405	2,098
	Total Production Cost (cents/1,000 gal)	22.3	18.0	16.0	13.3	11.2	9.0	20.0	15.4	13.3	10.5	8.2	5.8	18.0	13.3	11.2	8.2	5.8	16.0	11.2	9.0	5.8	14.0	9.0	6.6	11.2	5.8	9.0
>1,000,000	Total Capital Cost (K$)	161,568	127,865	112,981	92,805	77,017	60,609	142,313	108,125	92,805	71,818	55,164	37,607	127,865	92,805	77,017	55,164	37,607	112,981	77,017	60,609	37,607	797,780	60,609	43,379	77,017	37,607	60,609
517.491	O&M Cost (K$/year)	19,101	15,586	14,017	11,860	10,138	8,292	17,115	13,502	11,860	9,387	7,668	5,577	15,586	11,860	10,138	7,668	5,577	14,017	10,138	8,292	5,577	12,396	8,292	6,276	10,138	5,577	8,292
	Total Production Cost (cents/1,000 gal)	21.5	17.3	15.4	12.9	10.8	8.7	19.2	14.8	12.9	10.1	8.0	5.6	17.3	12.9	10.8	8.0	5.6	15.4	10.8	8.7	5.6	63.1	8.7	6.4	10.8	5.6	8.7

MGD= million gallons per day

Table 7-7 ESTIMATED COSTS FOR REMOVING VINYL CHLORIDE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	51	48	47	45	44	43	49	47	46	44	43	42	48	46	44	43	42	47	44	43	42	46	43	42	44	42	43
0.013	O&M Cost (K$/year)	0.6	0.6	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.4	0.6	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.4	0.5	0.5	0.4	0.5	0.4	0.5
	Total Production Cost (cents/1,000 gal)	158.7	148.4	143.1	138.4	135.8	132.7	151.5	142.0	138.9	134.7	131.6	126.4	148.4	138.9	135.8	131.6	126.4	143.1	135.8	132.7	126.4	140.0	132.7	127.5	135.8	126.4	132.7
101-500	Total Capital Cost (K$)	64	60	58	56	54	53	62	58	56	54	52	50	60	56	54	52	50	58	54	53	50	57	53	51	54	50	53
0.037	O&M Cost (K$/year)	1.0	0.9	0.8	0.8	0.7	0.7	0.9	0.8	0.8	0.7	0.7	0.6	0.9	0.8	0.7	0.7	0.6	0.8	0.7	0.7	0.6	0.8	0.7	0.6	0.7	0.6	0.7
	Total Production Cost (cents/1,000 gal)	71.0	66.0	64.0	62.0	59.0	57.0	68.0	63.0	62.0	59.0	57.0	54.0	66.0	62.0	59.0	57.0	54.0	64.0	59.0	57.0	54.0	62.0	57.0	55.0	59.0	54.0	57.0
501-1,000	Total Capital Cost (K$)	84	77	75	71	68	66	80	74	71	68	65	62	77	71	68	65	62	75	68	66	62	72	66	63	68	62	66
0.093	O&M Cost (K$/year)	1.8	1.6	1.5	1.4	1.3	1.2	1.7	1.5	1.4	1.3	1.2	1.1	1.6	1.4	1.3	1.2	1.1	1.5	1.3	1.2	1.1	1.4	1.2	1.1	1.3	1.1	1.2
	Total Production Cost (cents/1,000 gal)	38.3	35.2	33.9	32.2	30.8	29.4	36.6	33.5	32.2	30.5	29.1	27.7	35.2	32.2	30.8	29.1	27.7	33.9	30.8	29.4	27.7	32.5	29.4	28.0	30.8	27.7	29.4
1,001-3,300	Total Capital Cost (K$)	123	112	107	101	96	91	117	105	101	94	89	84	112	101	96	89	84	107	96	91	84	102	91	86	96	84	91
0.288	O&M Cost (K$/year)	4.2	3.7	3.5	3.3	3.0	2.8	4.0	3.5	3.3	3.0	2.8	2.5	3.7	3.3	3.0	2.8	2.5	3.5	3.0	2.8	2.5	3.3	2.8	2.6	3.0	2.5	2.8
	Total Production Cost (cents/1,000 gal)	20.3	18.5	17.4	16.4	15.4	14.6	19.2	17.2	16.4	15.2	14.4	13.5	18.5	16.4	15.4	14.4	13.5	17.4	15.4	14.6	13.5	16.6	14.6	13.8	15.4	13.5	14.6
3,301-10,000	Total Capital Cost (K$)	227	201	190	176	165	154	212	187	176	161	150	139	201	176	165	150	139	190	165	154	139	179	154	142	165	139	154
0.952	O&M Cost (K$/year)	13	11	11	10	9	9	12	10	10	9	8	8	11	10	9	8	8	11	9	9	8	10	9	8	9	8	9
	Total Production Cost (cents/1,000 gal)	12.4	11.0	10.4	9.6	9.0	8.4	11.6	10.2	9.6	8.8	8.2	7.6	11.0	9.6	9.0	8.2	7.6	10.4	9.0	8.4	7.6	9.8	8.4	7.8	9.0	7.6	8.4
10,001-25,000	Total Capital Cost (K$)	437	384	361	331	308	285	407	354	308	301	277	254	384	331	308	277	254	361	308	285	254	339	285	262	308	254	285
2.753	O&M Cost (K$/year)	34	30	29	27	25	23	32	28	25	24	23	21	30	27	25	23	21	29	25	23	21	27	23	22	25	21	23
	Total Production Cost (cents/1,000 gal)	9.2	8.1	7.7	7.0	6.6	6.1	8.6	7.5	6.6	6.4	5.9	5.5	8.1	7.0	6.6	5.9	5.5	7.7	6.6	6.1	5.5	7.2	6.1	5.6	6.6	5.5	6.1
25,001-50,000	Total Capital Cost (K$)	864	758	712	651	605	559	804	697	651	590	544	497	758	651	605	544	497	712	605	559	497	666	559	512	605	497	559
6.065	O&M Cost (K$/year)	75	67	63	58	55	51	71	62	58	54	50	46	67	58	55	50	46	63	55	51	46	60	51	47	55	46	51
	Total Production Cost (cents/1,000 gal)	8.6	7.6	7.2	6.6	6.1	5.7	8.0	7.0	6.6	6.0	5.5	5.1	7.6	6.6	6.1	5.5	5.1	7.2	6.1	5.7	5.1	6.7	5.7	5.2	6.1	5.1	5.7
50,001-75,000	Total Capital Cost (K$)	1,471	1,291	1,213	1,109	1,030	951	1,369	1,187	1,109	1,005	925	846	1,291	1,109	1,030	925	846	1,213	1,030	951	846	1,134	951	871	1,030	846	951
11.680	O&M Cost (K$/year)	140	124	117	108	101	95	131	115	108	99	92	86	124	108	101	92	86	117	101	95	86	110	95	88	101	86	95
	Total Production Cost (cents/1,000 gal)	7.9	7.0	6.6	6.0	5.6	5.2	7.4	6.4	6.0	5.5	5.1	4.7	7.0	6.0	5.6	5.1	4.7	6.6	5.6	5.2	4.7	6.1	5.2	4.8	5.6	4.7	5.2
75,000-100,000	Total Capital Cost (K$)	1,862	1,634	1,536	1,405	1,306	1,206	1,733	1,504	1,405	1,274	1,174	1,074	1,634	1,405	1,306	1,174	1,074	1,536	1,306	1,206	1,074	1,437	1,206	1,106	1,306	1,074	1,206
15.912	O&M Cost (K$/year)	188	167	158	146	137	128	176	155	146	134	125	116	167	146	137	125	116	158	137	128	116	149	128	119	137	116	128
	Total Production Cost (cents/1,000 gal)	7.5	6.6	6.3	5.8	5.4	5.0	7.0	6.1	5.8	5.2	4.9	4.5	6.6	5.8	5.4	4.9	4.5	6.3	5.4	5.0	4.5	5.9	5.0	4.6	5.4	4.5	5.0
100,001-500,000	Total Capital Cost (K$)	3,929	3,453	3,247	2,974	2,767	2,559	3,658	3,181	2,974	2,700	2,492	2,282	3,453	2,974	2,767	2,492	2,282	3,247	2,767	2,559	2,282	3,041	2,559	2,350	2,767	2,282	2,559
56.806	O&M Cost (K$/year)	424	377	356	329	308	288	397	349	329	302	281	261	377	329	308	281	261	356	308	288	261	336	288	268	308	261	288
	Total Production Cost (cents/1,000 gal)	7.1	6.2	5.9	5.4	5.1	4.7	6.6	5.8	5.4	4.9	4.6	4.2	6.2	5.4	5.1	4.6	4.2	5.9	5.1	4.7	4.2	5.5	4.7	4.3	5.1	4.2	4.7
500,001-1,000,000	Total Capital Cost (K$)	12,930	11,389	10,722	9,837	9,165	8,490	12,054	10,307	9,837	8,940	8,272	7,594	11,389	9,837	9,165	8,272	7,594	10,722	9,165	8,490	7,594	10,003	8,490	7,812	9,165	7,594	8,490
129.421	O&M Cost (K$/year)	1,490	1,323	1,251	1,156	1,084	1,012	1,390	1,220	1,156	1,061	989	918	1,323	1,156	1,084	989	918	1,251	1,084	1,012	918	1,179	1,012	941	1,084	918	1,012
	Total Production Cost (cents/1,000 gal)	6.8	6.0	5.7	5.2	4.9	4.5	6.4	5.6	5.2	4.8	4.4	4.1	6.0	5.2	4.9	4.4	4.1	5.7	4.9	4.5	4.1	5.3	4.5	4.2	4.9	4.1	4.5
>1,000,000	Total Capital Cost (K$)	48,382	42,707	40,252	36,995	34,522	32,039	45,155	39,460	36,995	33,723	31,238	28,742	42,707	36,995	34,522	31,238	28,742	40,252	34,522	32,039	28,742	37,790	32,039	29,547	34,522	28,742	32,039
517.491	O&M Cost (K$/year)	5,937	5,272	4,986	4,607	4,321	4,036	5,588	4,894	4,607	4,229	3,944	3,660	5,272	4,607	4,321	3,944	3,660	4,986	4,321	4,036	3,660	4,699	4,036	3,751	4,321	3,660	4,036
	Total Production Cost (cents/1,000 gal)	6.6	5.8	5.5	5.1	4.7	4.4	6.1	5.4	5.1	4.6	4.3	4.0	5.8	5.1	4.7	4.3	4.0	5.5	4.7	4.4	4.0	5.2	4.4	4.1	4.7	4.0	4.4

MGD= million gallons per day

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Table 7-8 ESTIMATED COSTS FOR REMOVING 1,1-DICHLOROETHYLENE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	54	50	49	47	46	44	52	48	47	45	44	42	50	47	46	44	42	49	46	44	42	48	44	43	46	42	44
0.013	O&M Cost (K$/year)	0.7	0.6	0.6	0.6	0.5	0.5	0.7	0.6	0.6	0.5	0.5	0.4	0.6	0.6	0.5	0.5	0.4	0.6	0.5	0.5	0.4	0.6	0.5	0.4	0.5	0.4	0.5
	Total Production Cost (cents/1,000 gal)	168.7	154.5	150.3	145.3	139.2	134.7	160.3	149.2	145.3	137.8	133.3	127.2	154.5	145.3	139.2	133.3	127.2	150.3	139.2	134.7	127.2	146.7	134.7	128.3	139.2	127.2	134.7
101-500	Total Capital Cost (K$)	69	64	62	59	56	54	66	61	59	56	53	51	64	59	56	53	51	62	56	54	51	60	54	52	56	51	54
0.037	O&M Cost (K$/year)	1.2	1.0	0.9	0.8	0.8	0.7	1.1	0.9	0.8	0.8	0.7	0.6	1.0	0.8	0.8	0.7	0.6	0.9	0.8	0.7	0.6	0.9	0.7	0.7	0.8	0.6	0.7
	Total Production Cost (cents/1,000 gal)	77.5	71.0	68.0	64.0	62.0	59.0	74.0	67.0	64.0	61.0	58.0	55.0	71.0	64.0	62.0	58.0	55.0	68.0	62.0	59.0	55.0	66.0	59.0	56.0	62.0	55.0	59.0
501-1,000	Total Capital Cost (K$)	92	84	80	75	71	68	88	79	75	70	66	63	84	75	71	66	63	80	71	68	63	76	68	64	71	63	68
0.093	O&M Cost (K$/year)	2.1	1.8	1.7	1.5	1.4	1.3	2.0	1.7	1.5	1.4	1.2	1.1	1.8	1.5	1.4	1.2	1.1	1.7	1.4	1.3	1.1	1.6	1.3	1.1	1.4	1.1	1.3
	Total Production Cost (cents/1,000 gal)	42.6	38.5	36.7	34.1	32.2	30.5	40.4	36.2	34.1	31.8	29.7	28.0	38.5	34.1	32.2	29.7	28.0	36.7	32.2	30.5	28.0	34.8	30.5	28.4	32.2	28.0	30.5
1,001-3,300	Total Capital Cost (K$)	141	125	117	108	101	94	132	115	108	99	92	85	125	108	101	92	85	117	101	94	85	110	94	87	101	85	94
0.280	O&M Cost (K$/year)	5.0	4.3	4.0	3.6	3.3	3.0	4.6	3.9	3.6	3.2	2.9	2.6	4.3	3.6	3.3	2.9	2.6	4.0	3.3	3.0	2.6	3.7	3.0	2.7	3.3	2.6	3.0
	Total Production Cost (cents/1,000 gal)	23.3	20.5	19.3	17.7	16.4	15.2	21.7	18.9	17.7	16.1	14.9	13.7	20.5	17.7	16.4	14.9	13.7	19.5	16.4	15.2	13.7	18.1	15.2	14.1	16.4	13.7	15.2
3,301-10,000	Total Capital Cost (K$)	266	229	213	192	177	161	245	206	192	172	156	141	229	192	177	156	141	213	177	161	141	198	161	146	177	141	161
0.952	O&M Cost (K$/year)	15	13	12	11	10	9	14	12	11	10	9	8	13	11	10	9	8	12	10	9	8	11	9	8	10	8	9
	Total Production Cost (cents/1,000 gal)	14.5	12.5	11.6	10.5	9.6	8.8	13.4	11.4	10.5	9.3	8.5	7.7	12.5	10.5	9.6	8.5	7.7	11.6	9.6	8.8	7.7	10.8	8.8	8.0	9.6	7.7	8.8
10,001-25,000	Total Capital Cost (K$)	519	442	409	366	333	301	475	399	366	323	290	259	442	366	333	290	259	409	333	301	259	376	301	269	333	259	301
2.753	O&M Cost (K$/year)	40	35	32	29	27	24	37	31	29	26	24	21	35	29	27	24	21	32	27	24	21	4	24	22	27	21	24
	Total Production Cost (cents/1,000 gal)	10.9	9.3	8.6	7.7	7.1	6.4	10.0	8.4	7.7	6.9	6.2	5.6	9.3	7.7	7.1	6.2	5.6	8.6	7.1	6.4	5.6	5.4	6.4	5.8	7.1	5.6	6.4
25,001-50,000	Total Capital Cost (K$)	1,027	874	808	721	655	590	940	787	721	634	570	508	874	721	655	570	508	808	655	590	508	742	590	527	655	508	590
6.060	O&M Cost (K$/year)	88	76	71	64	59	53	81	69	64	57	52	47	76	64	59	52	47	71	59	53	47	65	53	49	59	47	53
	Total Production Cost (cents/1,000 gal)	10.2	8.7	8.1	7.2	6.6	6.0	9.4	7.9	7.2	6.4	5.8	5.2	8.7	7.2	6.6	5.8	5.2	8.1	6.6	6.0	5.2	7.4	6.0	5.4	6.6	5.2	6.0
50,001-75,000	Total Capital Cost (K$)	1,750	1,489	1,376	1,227	1,115	1,005	1,601	1,340	1,227	1,079	970	864	1,489	1,227	1,115	970	864	1,376	1,115	1,005	864	1,264	1,005	897	1,115	864	1,005
11.680	O&M Cost (K$/year)	163	141	131	118	108	99	150	128	118	105	96	87	141	118	108	96	87	131	108	99	87	121	99	90	108	87	99
	Total Production Cost (cents/1,000 gal)	9.3	8.0	7.4	6.6	6.0	5.5	8.6	7.2	6.6	5.9	5.3	4.8	8.0	6.6	6.0	5.3	4.8	7.4	6.0	5.5	4.8	6.8	5.5	4.9	6.0	4.8	5.5
75,000-100,000	Total Capital Cost (K$)	2,213	1,884	1,742	1,554	1,413	1,274	2,026	1,696	1,554	1,368	1,230	1,096	1,884	1,554	1,413	1,230	1,096	1,742	1,413	1,274	1,096	1,600	1,274	1,139	1,413	1,096	1,274
15.912	O&M Cost (K$/year)	221	190	177	159	146	134	205	173	159	142	130	118	190	159	146	130	118	177	146	134	118	164	134	121	146	118	134
	Total Production Cost (cents/1,000 gal)	8.9	7.6	7.1	6.3	5.8	5.2	8.2	6.9	6.3	5.6	5.1	4.6	7.6	6.3	5.8	5.1	4.6	7.1	5.8	5.2	4.6	6.5	5.2	4.7	5.8	4.6	5.2
100,001-500,000	Total Capital Cost (K$)	4,662	3,975	3,678	3,286	2,991	2,700	4,271	3,583	3,286	2,897	2,608	2,330	3,975	3,286	2,991	2,608	2,330	3,678	2,991	2,700	2,330	3,382	2,700	2,418	2,991	2,330	2,700
36.886	O&M Cost (K$/year)	496	428	398	359	330	301	457	388	359	320	292	265	428	359	330	292	265	398	330	301	265	368	301	274	330	265	301
	Total Production Cost (cents/1,000 gal)	8.3	7.1	6.6	5.9	5.4	4.9	7.7	6.5	5.9	5.3	4.8	4.3	7.1	5.9	5.4	4.8	4.3	6.6	5.4	4.9	4.3	6.1	4.9	4.4	5.4	4.3	4.9
500,001-1,000,000	Total Capital Cost (K$)	15,307	13,079	12,118	10,847	9,892	8,949	14,040	11,808	10,847	9,586	8,650	7,748	13,079	10,847	9,892	8,650	7,748	12,118	9,892	8,949	7,748	11,156	8,949	8,033	9,892	7,748	8,949
129.421	O&M Cost (K$/year)	1,743	1,502	1,398	1,261	1,159	1,059	1,606	1,364	1,261	1,126	1,027	952	1,502	1,261	1,159	1,027	952	1,398	1,159	1,059	952	1,294	1,059	962	1,159	952	1,059
	Total Production Cost (cents/1,000 gal)	8.0	6.9	6.4	5.7	5.3	4.8	7.4	6.2	5.7	5.1	4.6	4.2	6.9	5.7	5.3	4.6	4.2	6.4	5.3	4.8	4.2	5.9	4.8	4.3	5.3	4.2	4.8
>1,000,000	Total Capital Cost (K$)	57,133	48,931	45,391	40,714	37,196	33,726	52,467	44,251	40,714	36,072	32,628	29,308	48,931	40,714	37,196	32,628	29,308	45,391	37,196	33,726	29,308	41,852	33,726	30,308	37,196	29,308	33,726
517.491	O&M Cost (K$/year)	6,500	5,983	5,570	5,026	4,619	4,220	6,397	5,437	5,026	4,489	4,094	3,717	5,983	5,026	4,619	4,094	3,717	5,570	4,619	4,220	3,717	5,158	4,219	3,836	4,619	3,717	4,220
	Total Production Cost (cents/1,000 gal)	7.5	6.6	6.2	5.5	5.1	4.6	7.1	6.0	5.5	4.9	4.5	4.0	6.6	5.5	5.1	4.5	4.0	6.2	5.1	4.6	4.0	5.7	4.6	4.2	5.1	4.0	4.6

MGD= million gallons per day

Table 7-9 ESTIMATED COSTS FOR REMOVING BENZENE BY PACKED TOWER AERATION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	62	56	54	51	49	46	59	53	51	48	46	43	56	51	49	46	43	54	49	46	43	52	46	44	49	43	46
0.013	O&M Cost (K$/year)	1.1	1.0	0.9	0.8	0.7	0.6	1.0	0.9	0.8	0.7	0.6	0.5	1.0	0.8	0.7	0.6	0.5	0.9	0.7	0.6	0.5	0.8	0.6	0.5	0.7	0.5	0.6
	Total Production Cost (cents/1,000 gal)	197.0	180.2	171.6	160.8	152.2	145.3	186.4	169.4	160.8	149.9	141.0	132.1	180.2	160.8	152.2	141.0	132.1	171.6	152.2	145.3	132.1	163.0	145.3	134.1	152.2	132.1	145.3
101-500	Total Capital Cost (K$)	82	74	70	65	61	58	78	69	65	60	56	53	74	65	61	56	53	70	61	58	53	66	58	54	61	53	58
0.037	O&M Cost (K$/year)	2.1	1.7	1.6	1.3	1.2	1.0	1.9	1.5	1.3	1.1	0.9	0.7	1.7	1.3	1.2	0.9	0.7	1.6	1.2	1.0	0.7	1.4	1.0	0.8	1.2	0.7	1.0
	Total Production Cost (cents/1,000 gal)	97.2	86.0	81.0	74.0	70.0	64.0	91.0	80.0	74.0	68.0	62.0	57.0	86.0	74.0	70.0	62.0	57.0	81.0	70.0	64.0	57.0	76.0	64.0	59.0	70.0	57.0	64.0
501-1,000	Total Capital Cost (K$)	115	101	95	86	80	74	107	93	86	78	71	66	101	86	80	71	66	95	80	74	66	88	74	68	90	66	74
0.093	O&M Cost (K$/year)	4.1	3.3	3.0	2.6	2.1	1.9	3.6	2.9	2.6	2.1	1.7	1.3	3.3	2.6	2.1	1.7	1.3	3.0	2.1	1.9	1.3	2.7	1.9	1.4	2.2	1.3	1.9
	Total Production Cost (cents/1,000 gal)	57.4	49.5	46.1	41.7	37.7	34.6	52.8	45.1	41.7	36.9	33.2	29.8	49.5	41.7	37.7	33.2	29.8	46.1	37.7	34.6	29.8	42.8	34.6	30.8	38.0	29.8	34.6
1,001-3,300	Total Capital Cost (K$)	188	160	148	131	119	106	172	144	131	115	102	91	160	131	119	102	91	148	119	106	91	135	106	95	119	91	106
0.280	O&M Cost (K$/year)	9.6	7.9	7.1	6.1	5.2	4.4	8.6	6.9	6.1	5.0	4.1	3.0	7.9	6.1	5.2	4.1	3.0	7.1	5.2	4.4	3.0	6.3	4.4	3.3	5.2	3.0	4.4
	Total Production Cost (cents/1,000 gal)	34.0	28.7	26.3	23.2	20.6	18.2	30.9	25.6	23.2	19.9	17.3	14.9	28.7	23.2	20.6	17.3	14.9	26.3	20.6	18.2	14.9	23.9	18.2	15.6	20.6	14.9	18.2
3,301-10,000	Total Capital Cost (K$)	353	325	295	254	223	192	305	285	254	213	181	156	325	254	223	181	156	295	223	192	156	264	192	164	223	156	192
0.952	O&M Cost (K$/year)	29	23	21	18	16	13	26	20	18	15	12	9	23	18	16	12	9	21	16	13	9	19	13	10	16	9	13
	Total Production Cost (cents/1,000 gal)	23.3	19.2	17.4	15.0	13.1	11.1	21.0	16.8	15.0	12.5	10.5	8.6	19.2	15.0	13.1	10.5	8.6	17.4	13.1	11.1	8.6	15.6	11.1	9.2	13.1	8.6	11.1
10,001-25,000	Total Capital Cost (K$)	804	690	617	519	443	371	761	594	519	417	354	301	690	519	443	354	301	617	443	371	301	543	371	318	443	301	371
2.753	O&M Cost (K$/year)	81	66	60	51	44	36	73	58	51	42	33	25	66	51	44	33	25	60	44	36	25	53	36	27	44	25	36
	Total Production Cost (cents/1,000 gal)	19.4	15.8	14.2	12.0	10.3	8.5	17.4	13.7	12.0	9.7	8.0	6.5	15.8	12.0	10.3	8.0	6.5	14.2	10.3	8.5	6.5	12.5	8.5	6.9	10.3	6.5	8.5
25,001-50,000	Total Capital Cost (K$)	1,727	1,391	1,242	1,042	885	731	1,537	1,194	1,042	834	697	591	1,391	1,042	885	697	591	1,242	885	731	591	1,091	731	626	885	591	731
6.060	O&M Cost (K$/year)	175	144	130	111	96	80	157	125	111	92	73	55	144	111	96	73	55	130	96	80	55	116	80	60	96	55	80
	Total Production Cost (cents/1,000 gal)	18.3	14.9	13.4	11.3	9.7	8.0	16.4	12.9	11.3	9.2	7.5	6.0	14.9	11.3	9.7	7.5	6.0	13.4	9.7	8.0	6.0	11.8	8.0	6.5	9.7	6.0	8.0
50,001-75,000	Total Capital Cost (K$)	2,989	2,403	2,145	1,797	1,524	1,246	2,657	2,061	1,797	1,435	1,189	1,005	2,403	1,797	1,524	1,189	1,005	2,145	1,524	1,246	1,005	1,883	1,246	1,065	1,524	1,005	1,246
11.680	O&M Cost (K$/year)	319	263	238	204	177	148	287	230	204	168	135	101	263	204	177	135	101	238	177	148	101	212	148	111	177	101	148
	Total Production Cost (cents/1,000 gal)	16.9	13.7	12.3	10.4	8.9	7.4	15.1	11.9	10.4	8.5	6.9	5.5	13.7	10.4	8.9	6.9	5.5	12.3	8.9	7.4	5.5	10.9	7.4	5.9	8.9	5.5	7.4
75,000-100,000	Total Capital Cost (K$)	3,821	3,071	2,741	2,290	1,947	1,580	3,396	2,634	2,290	1,832	1,505	1,273	3,071	2,290	1,947	1,505	1,273	2,741	1,947	1,580	1,273	2,405	1,580	1,349	1,947	1,273	1,580
15.912	O&M Cost (K$/year)	425	351	318	273	237	200	383	307	273	226	183	137	351	273	237	183	137	318	237	200	137	284	200	150	237	137	200
	Total Production Cost (cents/1,000 gal)	16.1	13.1	11.8	10.0	8.6	7.1	14.4	11.4	10.0	8.1	6.6	5.3	13.1	10.0	8.6	6.6	5.3	11.8	8.6	7.1	5.3	10.4	7.1	5.7	8.6	5.3	7.1
100,001-500,000	Total Capital Cost (K$)	8,130	6,538	5,836	4,888	4,147	3,380	7,228	5,608	4,888	3,904	3,184	2,699	6,538	4,888	4,147	3,184	2,699	5,836	4,147	3,380	2,699	5,121	3,380	2,858	4,147	2,699	3,380
35.806	O&M Cost (K$/year)	945	781	708	609	530	447	852	684	609	504	412	308	781	609	530	412	308	708	530	447	308	633	447	338	530	308	447
	Total Production Cost (cents/1,000 gal)	15.1	12.3	11.1	9.4	8.1	6.7	13.5	10.7	9.4	7.6	6.2	5.0	12.3	9.4	8.1	6.2	5.0	11.1	8.1	6.7	5.0	9.8	6.7	5.4	8.1	5.0	6.7
500,001-1,000,000	Total Capital Cost (K$)	26,956	21,693	19,375	16,239	13,791	11,252	23,976	18,620	16,239	12,985	10,524	8,943	21,693	16,239	13,791	10,524	8,943	19,375	13,791	11,252	8,943	17,012	11,252	9,462	13,791	8,943	11,252
129.421	O&M Cost (K$/year)	3,272	2,710	2,460	2,119	1,848	1,562	2,955	2,378	2,119	1,758	1,452	1,084	2,710	2,119	1,848	1,452	1,084	2,460	1,848	1,562	1,084	2,203	1,562	1,190	1,848	1,084	1,562
	Total Production Cost (cents/1,000 gal)	14.6	11.9	10.7	9.1	7.8	6.5	13.0	10.3	9.1	7.4	6.1	4.8	11.9	9.1	7.8	6.1	4.8	10.7	7.8	6.5	4.8	9.5	6.5	5.2	7.8	4.8	6.5
>1,000,000	Total Capital Cost (K$)	101,544	81,791	73,091	61,318	52,124	42,583	90,361	70,257	61,318	49,095	39,557	33,709	81,791	61,318	52,124	39,557	33,709	73,091	52,124	42,583	33,709	64,220	42,583	35,631	52,124	33,709	42,583
517.491	O&M Cost (K$/year)	12,863	10,673	9,698	8,366	7,310	6,191	11,626	9,379	8,366	6,958	5,798	4,323	10,673	8,366	7,310	5,798	4,323	9,698	7,310	6,191	4,323	8,696	6,191	4,745	7,310	4,323	6,191
	Total Production Cost (cents/1,000 gal)	14.0	11.4	10.3	8.8	7.6	6.3	12.6	9.9	8.8	7.2	5.9	4.7	11.4	8.8	7.6	5.9	4.7	10.3	7.6	6.3	4.7	9.2	6.3	5.0	7.6	4.7	6.3

MGD= million gallons per day

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Table 7-10. Estimated Costs for Removing p-Dichlorobenzene by Packed Tower Aeration

System Size Population Range Average Daily Flow (MGD)		Influent				
		1000 (ug/L)			500 (ug/L)	
		Effluent (ug/L)			Effluent (ug/L)	
		5	10	750	5	10
25-100	Total Capital Cost (K$)	66	63	42	63	59
0.013	O&M Cost (K$/year)	1.4	1.3	0.5	1.3	1.2
	Total Production Cost (cents/1,000 gal)	214.9	204.0	129.9	204.0	192.9
101-500	Total Capital Cost (K$)	91	85	51	85	80
0.037	O&M Cost (K$/year)	2.7	2.4	0.7	2.4	2.2
	Total Production Cost (cents/1,000 gal)	109.8	102.0	56.0	102.0	96.0
501-1,000	Total Capital Cost (K$)	131	122	64	122	113
0.093	O&M Cost (K$/year)	5.3	4.8	1.2	4.8	4.3
	Total Production Cost (cents/1,000 gal)	67.3	62.2	28.7	62.2	57.1
1,001-3,300	Total Capital Cost (K$)	225	206	87	206	187
0.280	O&M Cost (K$/year)	12.6	11.4	2.8	11.4	10.1
	Total Production Cost (cents/1,000 gal)	41.8	38.2	14.2	38.2	34.4
3,301-10,000	Total Capital Cost (K$)	504	454	146	454	402
0.952	O&M Cost (K$/year)	41	37	8	37	33
	Total Production Cost (cents/1,000 gal)	31.1	28.0	8.1	28.0	24.9
10,001-25,000	Total Capital Cost (K$)	1,167	1,047	277	1,047	925
2.753	O&M Cost (K$/year)	108	97	23	97	87
	Total Production Cost (cents/1,000 gal)	26.3	23.6	6.0	23.6	20.9
25,001-50,000	Total Capital Cost (K$)	2,372	2,125	543	2,125	1,874
6.065	O&M Cost (K$/year)	232	210	50	210	187
	Total Production Cost (cents/1,000 gal)	24.8	22.3	5.5	22.3	19.8
50,001-75,000	Total Capital Cost (K$)	4,115	3,685	924	3,685	3,248
11.680	O&M Cost (K$/year)	422	382	93	382	342
	Total Production Cost (cents/1,000 gal)	22.8	20.5	5.1	20.5	18.2
75,000-100,000	Total Capital Cost (K$)	5,265	4,713	1,173	4,713	4,154
15.912	O&M Cost (K$/year)	561	509	126	509	455
	Total Production Cost (cents/1,000 gal)	21.8	19.6	4.9	19.6	17.4
100,001-500,000	Total Capital Cost (K$)	11,207	10,034	2,489	10,034	8,844
36.806	O&M Cost (K$/year)	1,244	1,129	283	1,129	1,011
	Total Production Cost (cents/1,000 gal)	20.4	18.4	4.6	18.4	16.3
500,001-1,000,000	Total Capital Cost (K$)	37,165	33,285	8,264	33,285	29,349
129.421	O&M Cost (K$/year)	4,297	3,903	995	3,903	3,500
	Total Production Cost (cents/1,000 gal)	19.6	17.7	4.4	17.7	15.7
>1,000,000	Total Capital Cost (K$)	140,015	125,438	31,210	125,438	110,666
517.491	O&M Cost (K$/year)	16,847	15,315	3,968	15,315	13,749
	Total Production Cost (cents/1,000 gal)	18.8	17.0	4.3	17.0	15.1

MGD= million gallons per day

Table 7-11. Estimated Costs for Removing 1,1,1-Trichloroethane by Packed Tower Aeration

System Size Population Range Average Daily Flow (MGD)		Influent						
		500 (ug/L)			200 (ug/L)		100 (ug/L)	
		Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)	
		5	10	200	5	10	5	10
25-100	Total Capital Cost (K$)	52	50	43	50	48	48	46
0.013	O&M Cost (K$/year)	0.7	0.7	0.5	0.7	0.6	0.6	0.6
	Total Production Cost (cents/1,000 gal)	161.5	156.4	131.0	155.0	148.1	148.1	143.3
101-500	Total Capital Cost (K$)	66	64	52	63	60	60	58
0.037	O&M Cost (K$/year)	1.2	1.1	0.7	1.0	0.9	0.9	0.8
	Total Production Cost (cents/1,000 gal)	74.0	71.0	57.0	70.0	66.0	66.0	63.0
501-1,000	Total Capital Cost (K$)	87	83	65	82	78	78	74
0.093	O&M Cost (K$/year)	2.1	1.9	1.2	1.9	1.7	1.7	1.5
	Total Production Cost (cents/1,000 gal)	40.6	38.5	29.2	37.9	35.8	35.8	33.6
1,001-3,300	Total Capital Cost (K$)	131	124	89	121	114	114	107
0.280	O&M Cost (K$/year)	5.0	4.5	2.8	4.4	4.0	4.0	3.6
	Total Production Cost (cents/1,000 gal)	22.1	20.6	14.4	20.2	18.9	18.9	17.5
3,301-10,000	Total Capital Cost (K$)	246	230	150	224	207	207	189
0.952	O&M Cost (K$/year)	15	14	8.5	13	12	12	11
	Total Production Cost (cents/1,000 gal)	13.7	12.8	8.2	12.4	11.4	11.4	10.4
10,001-25,000	Total Capital Cost (K$)	505	461	280	447	403	403	360
2.753	O&M Cost (K$/year)	40	37	23	36	32	32.3	29
	Total Production Cost (cents/1,000 gal)	10.7	9.8	6.0	9.5	8.6	8.6	7.7
25,001-50,000	Total Capital Cost (K$)	996	911	550	882	795	795	709
6.065	O&M Cost (K$/year)	88	81	51	78	71	71	63.9
	Total Production Cost (cents/1,000 gal)	10.0	9.1	5.6	8.9	8.0	8.0	7.2
50,001-75,000	Total Capital Cost (K$)	1,693	1,552	930	1,503	1,354	1,354	1,207
11.680	O&M Cost (K$/year)	163	149	94	145	132	132	118.4
	Total Production Cost (cents/1,000 gal)	9.1	8.4	5.1	8.1	7.3	7.3	6.6
75,000-100,000	Total Capital Cost (K$)	2,136	1,963	1,200	1,903	1,714	1,714	1,529
15.912	O&M Cost (K$/year)	220	202	130	196	178	178	160
	Total Production Cost (cents/1,000 gal)	8.7	8.0	5.0	7.8	7.0	7.0	6.3
100,001-500,000	Total Capital Cost (K$)	4,489	4,141	2,500	4,013	3,620	3,620	3,232
36.806	O&M Cost (K$/year)	494	454	290	441	400	400	360.3
	Total Production Cost (cents/1,000 gal)	8.2	7.5	4.7	7.3	6.6	6.6	5.9
500,001-1,000,000	Total Capital Cost (K$)	14,716	13,618	8,300	13,207	11,932	11,932	10,673
129.421	O&M Cost (K$/year)	1,736	1,595	1,000	1,549	1,406	1,406	1,266
	Total Production Cost (cents/1,000 gal)	7.8	7.2	4.5	7.0	6.4	6.4	5.7
>1,000,000	Total Capital Cost (K$)	54,847	50,920	31,000	49,403	44,711	44,711	40,079
517.491	O&M Cost (K$/year)	6,920	6,356	4,000	6,173	5,606	5,606	5,048
	Total Production Cost (cents/1,000 gal)	7.6	7.0	4.3	6.8	6.1	6.1	5.5

MGD= million gallo MGD= million gallons per day

Table 7-12 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED TRICHLOROETHYLENE

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 268.50 (mg/cu.m)	Influent																									
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/l)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.05	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	51.7	46.8	44.0	39.2	34.4	27.9	49.2	43.0	39.2	32.6	24.4	12.8	46.8	39.2	34.4	24.4	12.8	44.0	34.4	27.9	12.8	40.5	27.9	16.8	34.4	12.8	27.9
	Air Concentration (mg/cu.m)	9.66	10.58	11.14	12.13	13.09	14.35	4.63	4.34	4.85	5.37	6.15	7.82	2.12	2.43	2.62	3.08	3.91	1.11	1.31	1.43	1.95	0.59	0.72	0.89	0.26	0.39	0.14
101-500	Effluent Water (lbs/day)	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00
0.057	Effluent Air (lbs/day)	0.15	0.15	0.15	0.15	0.14	0.12	0.06	0.06	0.06	0.08	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00
	Air:Water Ratio	43.0	39.2	37.0	33.2	29.0	22.8	41.0	36.2	33.2	27.2	20.4	12.2	39.2	33.2	29.0	20.4	12.2	37.0	29.0	22.8	12.2	34.2	22.8	14.3	29.0	12.2	22.8
	Air Concentration (mg/cu.m)	11.61	12.64	13.25	14.32	15.53	17.56	4.86	5.39	5.75	6.44	7.36	8.20	2.55	2.86	3.11	3.68	4.10	1.33	1.55	1.76	2.05	0.70	0.88	1.08	0.31	0.41	0.18
501-1,000	Effluent Water (lbs/day)	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	.00	.00	0.01	0.02	.00	.00	0.01	.00	.00	.00
0.095	Effluent Air (lbs/day)	0.39	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.12	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	.00	.00
	Air:Water Ratio	37.5	34.4	32.5	29.3	25.7	20.7	35.9	31.8	29.3	20.7	18.6	12.2	34.4	29.3	25.7	18.6	12.2	32.5	25.7	20.7	12.2	30.2	20.7	13.2	25.7	12.2	20.7
	Air Concentration (mg/cu.m)	13.32	14.40	15.09	16.22	17.52	19.34	5.58	6.14	6.49	8.46	8.07	8.20	2.88	3.24	3.50	4.04	4.10	1.51	1.75	1.93	2.05	0.80	0.97	1.14	0.35	0.41	0.19
1,001-3,300	Effluent Water (lbs/day)	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	.00	0.01	0.02	0.06	.00	0.01	0.02	.00	0.01	.00
0.280	Effluent Air (lbs/day)	1.17	1.16	1.14	1.11	1.05	0.93	0.46	0.46	0.44	0.41	0.35	0.23	0.25	0.22	0.21	0.18	0.12	0.11	0.11	0.09	0.06	0.06	0.05	0.04	0.02	0.01	0.01
	Air:Water Ratio	33.8	31.1	29.5	26.8	23.7	19.3	32.4	28.9	26.8	22.5	17.4	12.2	31.4	26.8	25.7	17.4	12.2	29.5	23.7	19.3	12.2	27.5	19.3	12.6	23.7	12.2	19.3
	Air Concentration (mg/cu.m)	14.77	15.93	16.62	17.74	19.00	20.74	6.15	6.75	7.09	7.78	8.63	8.20	3.19	3.55	3.80	4.31	4.10	1.66	1.90	2.07	2.05	0.87	1.04	1.19	0.38	0.41	0.21
3,301-10,000	Effluent Water (lbs/day)	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.01	0.04	0.08	0.20	0.01	0.04	0.08	0.01	0.04	0.01
0.952	Effluent Air (lbs/day)	3.96	3.93	3.89	3.77	3.57	3.18	1.58	1.55	1.51	1.39	1.19	0.79	0.79	0.75	0.71	0.60	0.40	0.39	0.36	0.32	0.20	0.19	0.16	0.12	0.07	0.04	0.03
	Air:Water Ratio	30.5	29.1	27.6	25.1	22.4	18.4	29.6	27.1	25.1	21.3	16.7	12.2	29.1	25.1	22.4	16.7	12.2	27.6	22.4	18.4	12.2	25.8	18.4	12.2	22.4	12.2	18.4
	Air Concentration (mg/cu.m)	16.16	17.02	17.77	18.94	20.10	21.76	6.73	7.20	7.58	8.22	8.99	8.20	3.40	3.75	4.02	4.49	4.10	1.78	2.01	2.18	2.05	0.93	1.09	1.23	0.40	0.41	0.22
10,001-25,000	Effluent Water (lbs/day)	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	0.02	0.11	0.23	0.57	0.02	0.11	0.23	0.02	0.11	0.02
2.753	Effluent Air (lbs/day)	11.46	11.37	11.26	10.91	10.34	9.19	4.57	4.48	4.37	4.02	3.45	2.30	2.27	2.18	2.07	1.72	1.15	1.13	1.03	0.92	0.57	0.55	0.46	0.34	0.21	0.11	0.09
	Air:Water Ratio	26.3	24.2	22.8	17.8	16.8	14.2	25.2	22.3	20.4	16.8	12.7	12.2	24.2	20.4	17.8	12.7	12.2	22.8	17.8	14.2	12.2	21.1	14.2	12.2	17.8	12.2	14.2
	Air Concentration (mg/cu.m)	18.99	20.47	21.31	26.71	26.81	28.19	7.90	8.75	9.32	10.42	11.82	8.20	4.09	4.66	5.06	5.91	4.10	2.15	2.53	2.82	2.05	1.14	1.41	1.23	0.51	0.41	0.28
25,001-50,000	Effluent Water (lbs/day)	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	0.05	0.25	0.51	1.27	0.05	0.25	0.51	0.05	0.25	0.05
6.065	Effluent Air (lbs/day)	25.26	25.05	24.80	24.04	22.78	20.24	10.07	9.87	9.62	8.86	7.59	5.06	5.01	4.81	4.56	3.80	2.53	2.48	2.28	2.02	1.27	1.21	1.01	0.76	0.46	0.25	0.20
	Air:Water Ratio	26.4	24.2	22.9	17.9	16.8	14.2	25.3	22.4	20.5	16.8	12.7	12.2	24.2	20.5	17.9	12.7	13.2	22.9	17.9	14.2	12.2	21.1	14.2	12.2	17.9	12.2	14.2
	Air Concentration (mg/cu.m)	18.92	20.47	21.41	26.36	26.81	28.19	7.87	8.71	9.28	10.42	11.82	8.20	4.09	4.64	5.03	5.91	4.10	2.14	2.52	2.82	2.05	1.14	1.41	1.23	0.50	0.41	0.28
50,001-75,000	Effluent Water (lbs/day)	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	0.10	0.49	0.97	2.44	0.10	0.49	0.97	0.10	0.49	0.10
11.680	Effluent Air (lbs/day)	48.64	48.25	47.76	46.30	43.86	38.99	19.40	19.01	18.52	17.06	14.62	9.75	9.63	9.26	8.77	7.31	4.87	4.78	4.39	3.90	2.44	2.34	1.95	1.46	0.88	0.49	0.39
	Air:Water Ratio	26.5	24.3	23.0	17.9	16.9	14.3	25.3	22.5	20.5	16.9	12.8	12.2	24.3	20.5	17.9	12.8	12.2	23.0	17.9	14.3	12.2	21.2	14.3	12.2	17.9	12.2	14.3
	Air Concentration (mg/cu.m)	18.84	20.39	21.52	26.36	26.65	27.99	7.87	8.67	9.28	10.36	11.73	8.20	4.08	4.64	5.03	5.86	4.10	2.13	2.52	2.80	2.05	1.13	1.40	1.23	0.50	0.41	0.28
75,000-100,000	Effluent Water (lbs/day)	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	0.13	0.66	1.33	3.32	0.13	0.66	1.33	0.13	0.66	0.13
15.912	Effluent Air (lbs/day)	66.26	65.73	65.06	63.07	59.75	53.11	26.42	25.89	25.23	23.24	19.92	13.28	13.15	12.61	11.95	9.96	6.64	6.51	5.98	5.31	3.32	3.19	2.66	1.99	1.20	0.66	0.53
	Air:Water Ratio	26.6	24.4	23.1	18.0	17.0	14.4	25.4	22.6	20.7	17.0	12.9	12.2	24.4	20.7	18.1	12.9	12.2	23.1	18.0	14.4	12.2	21.3	14.4	12.2	18.0	12.2	14.4
	Air Concentration (mg/cu.m)	18.77	20.30	21.25	26.41	26.49	27.80	7.84	8.63	9.19	10.30	11.64	8.20	4.06	4.59	4.98	5.82	4.10	2.12	2.50	2.78	2.05	1.13	1.39	1.23	0.50	0.41	0.28
100,001-500,000	Effluent Water (lbs/day)	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	0.3	1.5	3.1	7.7	0.3	1.5	3.1	0.3	1.5	0.3
35.806	Effluent Air (lbs/day)	153.3	152.0	150.8	145.9	138.2	122.9	61.1	59.9	58.4	53.8	46.1	30.7	30.4	29.2	27.6	23.0	15.4	15.1	13.8	12.3	7.7	7.4	6.1	4.6	2.8	1.5	1.2
	Air:Water Ratio	26.7	24.5	23.1	18.1	17.1	14.4	25.6	22.6	20.7	17.1	12.9	12.2	24.5	20.7	18.1	12.9	12.2	23.1	18.1	14.4	12.2	21.3	14.4	12.2	18.1	12.2	14.4
	Air Concentration (mg/cu.m)	18.70	20.22	21.23	26.26	26.34	27.80	7.78	8.63	9.19	10.24	11.64	8.20	4.04	4.59	4.98	5.82	4.10	2.12	2.49	2.78	2.05	1.13	1.39	1.23	0.50	0.41	0.28
500,001-1,000,000	Effluent Water (lbs/day)	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	1.1	5.4	10.8	27.0	1.1	5.4	10.8	1.1	5.4	1.1
129.421	Effluent Air (lbs/day)	538.9	534.6	529.2	513.0	486.0	432.0	214.9	210.6	205.2	189.0	162.0	108.0	[illegible]	102.6	97.2	81.0	54.0	52.9	48.6	43.2	27.0	25.9	21.6	16.2	9.7	5.4	4.3
	Air:Water Ratio	25.8	24.5	23.2	18.2	17.1	14.5	25.6	22.7	20.8	17.1	13.0	12.2	24.5	20.8	18.2	13.0	12.2	25.2	18.2	14.5	12.2	21.5	14.5	12.2	18.2	12.2	14.5
	Air Concentration (mg/cu.m)	18.63	20.22	21.14	26.12	26.34	27.61	7.78	8.60	9.14	10.24	11.50	8.20	4.04	4.57	4.98	5.77	4.10	2.11	2.47	2.76	2.05	1.12	1.38	1.23	0.49	0.41	0.28
>1,000,000	Effluent Water (lbs/day)	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	4.3	21.6	43.2	108.0	4.3	21.6	43.2	4.3	21.6	4.3
517.491	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	755.7	647.8	431.8	427.5	410.3	388.7	323.9	215.9	211.6	194.3	172.7	108.0	103.6	86.4	64.8	38.9	21.6	17.3
	Air:Water Ratio	25.9	24.6	23.3	18.2	17.2	14.5	25.7	22.8	20.9	17.2	13.0	12.2	24.6	20.9	18.2	13.0	12.2	23.3	18.2	14.5	12.2	21.5	14.5	12.2	18.2	12.2	14.5
	Air Concentration (mg/cu.m)	18.56	20.14	21.05	26.12	26.18	27.61	7.75	8.56	9.10	10.18	11.50	8.20	4.03	4.55	4.93	5.77	4.10	2.10	2.47	2.76	2.05	1.12	1.38	1.23	0.49	0.41	0.28

MGD= million gallons per day
mg/cu.m= milligrams per cubic meter

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Table 7-15 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED TETRACHLOROETHYLENE

System Size Population Range verage Daily Flow (MGD)	Threshold Limit Value (TLV) 338.87 (mg/cu.m)	Influent																													
		500 (ug/L)							200 (ug/L)							100 (ug/L)						50 (ug/L)					25 (ug/L)				10 (u
		Effluent (ug/L)							Effluent (ug/L)							Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent
		1	5	10	15	25	50	100	1	5	10	15	25	50	100	1	5	10	15	25	50	1	5	10	15	25	1	5	10	15	1
25-100	Effluent Water (lbs/day)	.00	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	35.1	31.9	29.9	28.5	26.8	22.4	16.6	33.4	29.2	26.8	24.5	20.6	13.5	12.2	31.9	26.8	22.4	19.1	13.5	12.2	29.9	22.4	16.6	12.7	12.2	27.7	16.6	12.2	12.2	22.4
	Air Concentration (mg/cu.m)	14.23	15.55	16.40	17.03	17.74	20.10	24.11	5.96	6.68	7.09	7.56	8.50	11.12	8.20	3.11	3.55	4.0	4.45	5.56	4.10	1.64	2.01	2.41	2.76	2.05	0.87	1.21	1.25	0.82	0.40
101-500	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.02	0.05	.00	.00	.00	.00	0.01	0.02	0.05	.00	.00	.00	.00	0.01	0.02	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00
0.017	Effluent Air (lbs/day)	0.15	0.15	0.15	0.15	0.15	0.14	0.12	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00
	Air:Water Ratio	29.1	26.1	24.2	22.9	21.0	17.8	13.6	27.7	23.5	21.0	19.2	16.6	12.9	12.2	26.1	21.0	17.8	15.5	12.9	12.2	24.2	17.8	15.6	12.2	12.2	21.9	15.6	12.2	12.2	17.8
	Air Concentration (mg/cu.m)	17.16	18.98	20.26	21.19	22.64	25.30	29.43	7.19	8.30	9.05	9.64	10.55	11.64	8.20	3.80	4.53	5.06	5.49	5.82	4.10	2.03	2.53	2.94	2.87	2.05	1.10	1.47	1.25	0.82	0.51
501-1,000	Effluent Water (lbs/day)	.00	.00	0.01	0.01	0.02	0.04	0.08	.00	.00	0.01	0.01	0.02	0.04	0.08	.00	.00	0.01	0.01	0.02	0.04	.00	.00	0.01	0.01	0.02	.00	.00	0.01	0.01	.00
0.093	Effluent Air (lbs/day)	0.39	0.38	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.14	0.12	0.08	0.08	0.07	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01
	Air:Water Ratio	24.7	22.5	21.1	20.1	18.6	16.0	12.3	23.6	20.5	18.6	17.2	14.9	12.2	12.2	22.5	18.6	16.0	14.0	12.2	12.2	21.1	16.0	12.3	12.2	12.2	19.5	12.5	12.2	12.2	16.0
	Air Concentration (mg/cu.m)	20.22	22.02	23.24	24.15	25.56	28.15	32.54	8.44	9.52	10.22	10.76	11.75	12.30	8.20	4.40	5.11	5.63	6.08	6.15	4.10	2.32	2.81	3.25	2.87	2.05	1.24	1.63	1.25	0.82	0.96
1,001-3,300	Effluent Water (lbs/day)	.00	0.01	0.02	0.04	0.06	0.12	0.23	.00	0.01	0.02	0.04	0.06	0.12	0.23	.00	0.01	0.02	0.04	0.06	0.12	.00	0.01	0.02	0.04	0.06	.00	0.01	0.02	0.04	.00
0.280	Effluent Air (lbs/day)	1.17	1.16	1.14	1.13	1.11	1.05	0.93	0.46	0.46	0.44	0.43	0.41	0.35	0.23	0.23	0.22	0.21	0.20	0.18	0.12	0.11	0.11	0.09	0.08	0.06	0.06	0.05	0.04	0.02	0.02
	Air:Water Ratio	22.2	20.3	19.2	18.3	17.1	14.8	12.2	21.2	18.7	17.1	15.8	13.9	12.2	12.2	20.3	17.1	14.8	13.0	12.2	12.2	19.2	14.8	12.2	12.2	12.2	17.7	12.2	12.2	12.2	14.8
	Air Concentration (mg/cu.m)	22.49	24.40	25.54	26.52	27.80	30.45	32.81	9.39	10.44	11.12	11.72	12.60	12.30	8.20	4.80	5.56	6.09	6.54	6.15	4.10	2.55	3.04	3.28	2.87	2.05	1.36	1.64	1.25	0.82	0.61
3,301-10,000	Effluent Water (lbs/day)	0.01	0.04	0.08	0.12	0.20	0.40	0.79	0.01	0.04	0.08	0.12	0.20	0.40	0.79	0.01	0.04	0.08	0.12	0.20	0.40	0.01	0.04	0.08	0.12	0.20	0.01	0.04	0.08	0.12	0.01
0.952	Effluent Air (lbs/day)	3.96	3.93	3.89	3.85	3.77	3.57	3.18	1.58	1.55	1.51	1.47	1.39	1.19	0.79	0.79	0.75	0.71	0.68	0.60	0.40	0.39	0.36	0.32	0.28	0.20	0.19	0.16	0.12	0.08	0.07
	Air:Water Ratio	20.7	19.0	18.0	17.3	16.1	14.1	12.2	19.8	17.6	16.1	15.0	12.2	12.2	12.2	19.0	16.1	14.1	12.5	12.2	12.2	18.0	14.1	12.2	12.2	12.2	16.7	12.2	12.2	12.2	14.1
	Air Concentration (mg/cu.m)	24.12	26.07	27.24	28.06	29.52	31.94	32.81	10.06	11.09	11.81	12.34	14.35	12.30	8.20	5.21	5.90	6.39	6.81	6.15	4.10	2.72	3.19	3.28	2.87	2.05	1.44	1.64	1.25	0.82	0.64
10,001-25,000	Effluent Water (lbs/day)	0.02	0.11	0.23	0.34	0.57	1.15	2.30	0.02	0.11	0.23	0.34	0.57	1.15	2.30	0.02	0.11	0.23	0.34	0.57	1.15	0.02	0.11	0.23	0.34	0.57	0.02	0.11	0.23	0.34	0.02
2.753	Effluent Air (lbs/day)	11.46	11.37	11.26	11.14	10.91	10.34	9.19	4.57	4.48	4.37	4.25	4.02	3.45	2.30	2.27	2.18	2.07	1.95	1.72	1.15	1.13	1.03	0.92	0.80	0.57	0.55	0.46	0.34	0.23	0.21
	Air:Water Ratio	16.5	14.8	13.8	13.1	12.2	12.2	12.2	15.6	13.4	12.2	12.2	12.2	12.2	12.2	14.8	12.2	12.2	12.2	12.2	12.2	13.8	12.2	12.2	12.2	12.2	12.5	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	30.26	33.47	35.55	37.05	38.96	36.91	32.81	12.77	14.56	15.59	15.18	14.35	12.30	8.20	6.69	7.79	7.38	6.97	6.15	4.10	3.55	3.69	3.28	2.87	2.05	1.92	1.64	1.25	0.82	0.74
25,001-50,000	Effluent Water (lbs/day)	0.05	0.25	0.51	0.76	1.27	2.53	5.06	0.05	0.25	0.51	0.76	1.27	2.53	5.06	0.05	0.25	0.51	0.76	1.27	2.53	0.05	0.25	0.51	0.76	1.27	0.05	0.25	0.51	0.76	0.05
6.065	Effluent Air (lbs/day)	25.26	25.05	24.80	24.55	24.04	22.78	20.24	10.07	9.87	9.62	9.36	8.86	7.59	5.06	5.01	4.81	4.56	4.30	3.80	2.53	2.48	2.28	2.02	1.77	1.27	1.21	1.01	0.76	0.51	0.46
	Air:Water Ratio	16.6	15.0	13.9	13.2	12.2	12.2	12.2	15.8	13.6	12.2	12.2	12.2	12.2	12.2	15.0	12.2	12.2	12.2	12.2	12.2	13.9	12.2	12.2	12.2	12.2	12.6	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	30.08	33.02	35.28	36.77	38.96	36.91	32.81	12.60	14.35	15.59	15.18	14.35	12.30	8.20	6.60	7.79	7.38	6.97	6.15	4.10	3.53	3.69	3.28	2.87	2.05	1.91	1.64	1.25	0.82	0.74
50,001-75,000	Effluent Water (lbs/day)	0.10	0.49	0.97	1.46	2.44	4.87	9.75	0.10	0.49	0.97	1.46	2.44	4.87	9.75	0.10	0.49	0.97	1.46	2.44	4.87	0.10	0.49	0.97	1.46	2.44	0.10	0.49	0.97	1.46	0.10
11.640	Effluent Air (lbs/day)	48.64	48.25	47.76	47.27	46.30	43.86	38.99	19.40	19.01	18.52	18.03	17.06	14.62	9.75	9.65	9.26	8.77	8.28	7.31	4.87	4.78	4.39	3.90	3.41	2.44	2.36	1.95	1.46	0.97	0.88
	Air:Water Ratio	16.8	15.1	14.1	13.4	12.3	12.2	12.2	15.9	13.7	12.3	12.2	12.2	12.2	12.2	15.1	12.3	12.2	12.2	12.2	12.2	14.1	12.2	12.2	12.2	12.2	12.8	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	29.72	32.81	34.78	36.22	38.65	36.91	32.81	12.52	14.24	15.46	15.18	14.35	12.30	8.20	6.96	7.73	7.38	6.97	6.15	4.10	3.48	3.69	3.28	2.87	2.05	1.88	1.64	1.25	0.82	0.74
75,000-100,000	Effluent Water (lbs/day)	0.13	0.66	1.33	1.99	3.32	6.64	13.28	0.13	0.66	1.33	1.99	3.32	6.64	13.28	0.13	0.66	1.33	1.99	3.32	6.64	0.13	0.66	1.33	1.99	3.32	0.13	0.66	1.33	1.99	0.13
15.912	Effluent Air (lbs/day)	66.36	65.73	65.06	64.40	63.07	59.75	53.11	26.42	25.89	25.23	24.57	23.24	19.92	13.28	13.15	12.61	11.95	11.29	9.96	6.64	6.51	5.98	5.31	4.65	3.32	3.19	2.66	1.99	1.33	1.20
	Air:Water Ratio	17.0	15.3	14.3	13.5	12.4	12.2	12.2	16.1	13.9	12.4	12.2	12.2	12.2	12.2	15.3	12.4	12.2	12.2	12.2	12.2	14.3	12.2	12.2	12.2	12.2	12.9	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	29.37	32.38	34.29	35.95	38.33	36.91	32.81	12.57	14.04	15.33	15.18	14.35	12.30	8.20	6.48	7.67	7.38	6.97	6.15	4.10	3.43	3.69	3.28	2.87	2.05	1.86	1.64	1.25	0.82	0.74
100,001-500,000	Effluent Water (lbs/day)	0.3	1.5	3.1	4.6	7.7	15.4	30.7	0.3	1.5	3.1	4.6	7.7	15.4	30.7	0.3	1.5	3.1	4.6	7.7	15.4	0.3	1.5	3.1	4.6	7.7	0.3	1.5	3.1	4.6	0.3
56.806	Effluent Air (lbs/day)	153.3	152.0	150.5	149.0	145.9	138.2	122.9	61.1	59.9	58.4	56.8	53.8	46.1	30.7	30.4	29.2	27.6	26.1	23.0	15.4	15.1	13.8	12.3	10.8	7.7	7.4	6.1	4.6	3.1	2.8
	Air:Water Ratio	17.1	15.4	14.4	13.7	12.6	12.2	12.2	16.3	14.0	12.6	12.2	12.2	12.2	12.2	15.4	12.6	12.2	12.2	12.2	12.2	14.4	12.2	12.2	12.2	12.2	13.1	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	29.20	32.17	34.05	35.43	37.73	36.91	32.81	12.22	13.94	15.09	15.18	14.35	12.30	8.20	6.43	7.55	7.38	6.97	6.15	4.10	3.41	3.69	3.28	2.87	2.05	1.85	1.64	1.27	0.82	0.74
00,001-1,000,000	Effluent Water (lbs/day)	1.1	5.4	10.8	16.2	27.0	54.0	108.0	1.1	5.4	10.8	16.2	27.0	54.0	108.0	1.1	5.4	10.8	16.2	27.0	54.0	1.1	5.4	10.8	16.2	27.0	1.1	5.4	10.8	16.2	1.1
139.421	Effluent Air (lbs/day)	538.9	534.6	529.2	523.8	513.0	486.0	432.0	214.9	210.6	205.2	199.8	189.0	162.0	108.0	106.9	102.6	97.2	91.8	81.0	54.0	52.9	48.6	43.2	37.8	27.0	25.9	21.6	16.2	10.8	9.7
	Air:Water Ratio	17.3	15.6	14.5	13.8	12.7	12.2	12.2	16.4	14.2	12.7	12.2	12.2	12.2	12.2	15.6	12.7	12.2	12.2	12.2	12.2	14.5	12.2	12.2	12.2	12.2	13.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	28.87	31.75	33.82	35.17	37.43	36.91	32.81	12.14	13.74	14.97	15.18	14.35	12.30	8.20	6.35	7.49	7.38	6.97	6.15	4.10	3.38	3.69	3.28	2.87	2.05	1.82	1.64	1.25	0.82	0.74
>1,000,000	Effluent Water (lbs/day)	4.3	21.6	43.2	64.8	108.0	215.9	431.8	4.3	21.6	43.2	64.8	108.0	215.9	431.8	4.3	21.6	43.2	64.8	108.0	215.9	4.3	21.6	43.2	64.8	108.0	4.3	21.6	43.2	64.8	4.3
517.491	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,094.5	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	798.9	755.7	647.8	431.8	427.5	410.3	388.7	367.1	323.9	215.9	211.6	194.3	172.7	151.1	108.0	103.6	86.4	64.8	43.2	38.9
	Air:Water Ratio	17.5	15.7	14.7	13.9	12.8	12.2	12.2	16.6	14.3	12.8	12.2	12.2	12.2	12.2	15.7	12.8	12.2	12.2	12.2	12.2	14.7	12.2	12.2	12.2	12.2	13.3	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	28.54	31.55	33.36	14.92	37.14	36.91	32.81	12.00	13.65	14.85	15.18	14.35	12.30	8.20	6.31	7.43	7.38	6.97	6.15	4.10	3.34	3.69	3.28	2.87	2.05	1.81	1.64	1.25	0.82	0.74

D = million gallons per day

g/cu.m = milligrams per cubic meter

Table 7-14 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED CARBON TETRACHLORIDE

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 31.43 (mg/cu.m)	Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/l)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.05	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	35.9	32.5	30.5	27.3	23.0	17.1	34.1	29.8	27.3	21.1	14.9	12.5	32.5	27.5	25.0	14.9	12.5	30.5	25.0	17.1	12.5	28.2	17.1	12.5	23.0	12.5	17.1
	Air Concentration (mg/cu.m)	13.91	15.24	16.08	17.41	19.58	23.41	5.84	6.55	6.96	8.30	10.07	8.01	5.05	3.48	3.92	5.04	4.00	1.61	1.96	2.34	2.00	0.85	1.17	1.20	0.39	0.40	0.25
101-500	Effluent Water (lbs/day)	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00
0.037	Effluent Air (lbs/day)	0.15	0.15	0.18	0.15	0.14	0.12	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00
	Air:Water Ratio	29.8	26.8	24.8	21.6	18.3	14.0	28.5	24.1	21.6	17.1	12.5	12.5	26.8	21.6	18.3	12.5	12.5	24.8	18.3	14.0	12.5	22.5	14.0	12.5	18.3	12.5	14.0
	Air Concentration (mg/cu.m)	16.76	18.48	19.77	22.01	24.61	28.59	6.99	8.10	8.88	10.24	12.01	8.01	3.70	4.40	4.92	6.00	4.00	1.98	2.46	2.86	2.00	1.07	1.43	1.20	0.49	0.40	0.29
501-1,000	Effluent Water (lbs/day)	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	.00	.00	0.01	0.02	.00	.00	0.01	.00	.00	.00
0.093	Effluent Air (lbs/day)	0.39	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.12	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	.00	.00
	Air:Water Ratio	25.4	23.1	21.7	19.1	16.5	12.7	24.2	21.1	19.1	15.4	12.7	12.5	23.1	19.1	16.5	12.5	12.5	21.7	16.5	12.7	12.5	19.8	12.7	12.5	16.5	12.5	12.7
	Air Concentration (mg/cu.m)	19.66	21.44	22.60	24.89	27.29	31.52	8.23	9.25	9.95	11.37	11.82	8.01	4.29	4.98	5.46	6.00	4.00	2.26	2.73	3.15	2.00	1.21	1.58	1.20	0.55	0.40	0.32
1,001-3,300	Effluent Water (lbs/day)	.00	0.01	0.02	0.06	0.12	0.25	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	.00	0.01	0.02	0.06	.00	0.01	0.02	.00	0.01	.00
0.280	Effluent Air (lbs/day)	1.17	1.16	1.14	1.11	1.05	0.93	0.46	0.46	0.44	0.41	0.35	0.23	0.23	0.22	0.21	0.18	0.12	0.11	0.11	0.09	0.06	0.06	0.05	0.04	0.02	0.01	0.01
	Air:Water Ratio	22.0	20.5	19.7	17.6	15.3	12.5	21.9	19.3	17.6	14.3	12.5	12.5	20.9	17.6	15.3	12.5	12.5	19.7	15.3	12.5	12.5	18.2	12.5	12.5	15.3	12.5	12.5
	Air Concentration (mg/cu.m)	21.90	23.70	24.89	27.01	29.43	32.02	9.09	10.11	10.80	12.25	12.01	8.01	4.74	5.40	5.69	6.00	4.00	2.49	2.94	3.20	2.00	1.52	1.60	1.20	0.59	0.40	0.32
3,301-10,000	Effluent Water (lbs/day)	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.01	0.04	0.08	0.20	0.01	0.04	0.08	0.01	0.04	0.01
0.952	Effluent Air (lbs/day)	3.96	3.93	3.89	3.77	3.57	3.18	1.58	1.55	1.51	1.39	1.19	0.79	0.79	0.75	0.71	0.60	0.40	0.39	0.36	0.32	0.20	0.19	0.16	0.12	0.07	0.04	0.03
	Air:Water Ratio	21.3	19.6	18.5	16.6	14.5	12.8	20.4	18.1	16.6	13.7	12.5	12.5	19.6	16.6	14.5	12.5	12.5	18.5	14.5	12.5	12.5	17.2	12.5	12.5	14.5	12.5	12.5
	Air Concentration (mg/cu.m)	23.44	25.27	26.51	28.64	31.06	32.02	9.76	10.78	11.45	12.18	12.01	8.01	5.05	5.75	6.21	6.00	4.00	2.65	3.11	3.20	2.00	1.40	1.60	1.20	0.62	0.40	0.32
10,001-25,000	Effluent Water (lbs/day)	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	0.02	0.11	0.23	0.57	0.02	0.11	0.23	0.02	0.11	0.02
2.753	Effluent Air (lbs/day)	11.46	11.37	11.26	10.91	10.34	9.19	4.57	4.48	4.37	4.02	3.45	2.30	2.27	2.18	2.07	1.72	1.15	1.13	1.03	0.92	0.57	0.55	0.46	0.34	0.21	0.11	0.09
	Air:Water Ratio	17.0	15.4	14.3	12.5	12.5	12.5	16.2	13.9	12.5	12.5	12.5	12.5	15.4	12.5	12.5	12.5	12.5	14.3	12.5	12.5	12.5	13.0	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	29.37	32.17	34.29	38.03	36.03	32.02	12.29	14.04	15.21	14.01	12.01	8.01	6.43	7.61	7.21	6.00	4.00	3.43	3.60	3.20	2.00	1.85	1.60	1.20	0.72	0.40	0.32
25,001-50,000	Effluent Water (lbs/day)	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	0.05	0.25	0.51	1.27	0.05	0.25	0.51	0.05	0.25	0.05
6.068	Effluent Air (lbs/day)	25.26	25.05	24.80	24.04	22.78	20.24	10.07	9.87	9.62	8.86	7.59	5.06	5.01	4.81	4.56	3.80	2.53	2.48	2.28	2.02	1.27	1.21	1.01	0.76	0.46	0.25	0.20
	Air:Water Ratio	17.2	15.5	14.4	12.6	12.5	12.5	16.3	14.0	12.6	12.5	12.5	12.5	15.5	12.6	12.5	12.5	12.5	14.4	12.5	12.5	12.5	13.1	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	29.03	31.96	34.08	37.73	36.03	32.02	12.22	13.94	15.09	14.01	12.01	8.01	6.59	7.55	7.21	6.00	4.00	3.41	3.60	3.20	2.00	1.85	1.60	1.20	0.72	0.40	0.32
50,001-75,000	Effluent Water (lbs/day)	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	0.10	0.49	0.97	2.44	0.10	0.49	0.97	0.10	0.49	0.10
11.680	Effluent Air (lbs/day)	48.64	48.25	47.76	46.30	43.86	38.99	19.40	19.01	18.52	17.06	14.62	9.75	9.65	9.26	8.77	7.31	4.87	4.78	4.39	3.90	2.44	2.34	1.95	1.46	0.88	0.49	0.39
	Air:Water Ratio	17.3	15.6	14.6	12.7	12.5	12.5	16.5	14.2	12.7	12.5	12.5	12.5	15.6	12.7	12.5	12.5	12.5	14.6	12.5	12.5	12.5	13.2	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	28.87	31.75	33.59	37.43	36.03	32.02	12.07	13.74	14.97	14.01	12.01	8.01	6.55	7.49	7.21	6.00	4.00	3.36	3.60	3.20	2.00	1.82	1.60	1.20	0.72	0.40	0.32
75,000-100,000	Effluent Water (lbs/day)	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	0.13	0.66	1.33	3.32	0.13	0.66	1.33	0.13	0.66	0.13
15.912	Effluent Air (lbs/day)	66.26	65.73	65.06	63.07	59.75	53.11	26.42	25.89	25.23	23.24	19.92	13.28	13.15	12.61	11.95	9.96	6.64	6.51	5.98	5.31	3.32	3.19	2.66	1.99	1.20	0.66	0.53
	Air:Water Ratio	17.5	15.8	14.7	12.9	12.5	12.5	16.6	14.3	12.9	12.5	12.5	12.5	15.8	12.9	12.5	12.5	12.5	14.7	12.5	12.5	12.5	13.4	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	28.54	31.35	33.36	36.85	36.03	32.02	12.00	13.65	14.74	14.01	12.01	8.01	6.27	7.37	7.21	6.00	4.00	3.34	3.60	3.20	2.00	1.79	1.60	1.20	0.72	0.40	0.32
100,001-500,000	Effluent Water (lbs/day)	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	0.3	1.5	3.1	7.7	0.3	1.5	3.1	0.3	1.5	0.3
36.806	Effluent Air (lbs/day)	153.3	152.0	150.5	145.9	138.2	122.9	61.1	59.9	58.4	53.8	46.1	30.7	30.4	29.2	27.6	23.0	15.4	15.1	13.8	12.3	7.7	7.4	6.1	4.6	2.8	1.5	1.2
	Air:Water Ratio	17.7	15.9	14.9	13.0	12.5	12.5	16.8	14.5	13.0	12.5	12.5	12.5	15.9	13.0	12.5	12.5	12.5	14.9	12.5	12.5	12.5	13.5	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	28.21	31.16	32.91	36.57	36.03	32.02	11.88	13.46	14.63	14.01	12.01	8.01	6.23	7.31	7.21	6.00	4.00	3.29	3.60	3.20	2.00	1.78	1.60	1.20	0.72	0.40	0.32
500,001-1,000,000	Effluent Water (lbs/day)	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	1.1	5.4	10.8	27.0	1.1	5.4	10.8	1.1	5.4	1.1
129.421	Effluent Air (lbs/day)	538.9	534.6	529.2	513.0	486.0	432.0	214.9	210.6	205.2	189.0	162.0	108.0	106.9	102.6	97.2	81.0	54.0	52.9	48.6	43.2	27.0	25.9	21.6	16.2	9.7	5.4	4.3
	Air:Water Ratio	17.8	16.1	15.0	13.1	12.5	12.5	16.9	14.6	13.1	12.5	12.5	12.5	16.1	13.1	12.5	12.5	12.5	15.0	12.5	12.5	12.5	13.6	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	28.05	30.77	32.65	36.29	36.03	32.02	11.78	13.57	14.51	14.01	12.01	8.01	6.15	7.26	7.21	6.00	4.00	3.27	3.60	3.20	2.00	1.77	1.60	1.20	0.72	0.40	0.32
>1,000,000	Effluent Water (lbs/day)	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	4.3	21.6	43.2	108.0	4.3	21.6	43.2	4.3	21.6	4.3
517.491	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	755.7	647.8	431.8	427.5	410.3	388.7	323.9	215.9	211.6	194.3	172.7	108.0	103.6	86.4	64.8	38.9	21.6	17.3
	Air:Water Ratio	18.0	16.2	15.1	13.2	12.5	12.5	17.1	14.7	13.2	12.5	12.5	12.5	16.2	13.2	12.5	12.5	12.5	15.1	12.5	12.5	12.5	13.8	12.5	12.5	12.5	12.5	12.5
	Air Concentration (mg/cu.m)	27.74	30.58	32.47	36.01	36.03	32.02	11.68	13.28	14.40	14.01	12.01	8.01	6.12	7.20	7.21	6.00	4.00	3.25	3.60	3.20	2.00	1.74	1.60	1.20	0.72	0.40	0.32

MGD= million gallons per day
mg/cu.m=milligrams per cubic meter

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Table 7-15 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED 1,2-DICHLOROETHANE

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 40.44 (mg/cu.m)	Influent																									
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/l)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.08	0.08	0.08	0.08	0.08	0.04	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	159.5	145.5	137.3	123.1	108.5	88.7	152.5	134.3	123.1	102.8	80.9	49.7	145.5	125.1	108.5	80.9	49.7	137.3	108.5	88.7	49.7	127.0	88.7	61.1	108.5	49.7	88.7
	Air Concentration (mg/cu.m)	3.13	3.40	3.57	3.86	4.15	4.51	1.31	1.45	1.54	1.70	1.86	2.01	0.68	0.77	0.83	0.95	1.01	0.36	0.42	0.45	0.50	0.19	0.23	0.25	0.08	0.10	0.05
101-500	Effluent Water (lbs/day)	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00
0.037	Effluent Air (lbs/day)	0.15	0.15	0.15	0.15	0.14	0.12	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00
	Air:Water Ratio	139.7	128.1	121.2	109.0	96.3	78.9	133.7	118.6	109.0	91.3	72.0	44.1	128.1	109.0	96.3	72.0	44.1	121.2	96.3	78.9	44.1	112.5	78.9	54.5	96.3	44.1	78.9
	Air Concentration (mg/cu.m)	3.57	3.87	4.05	4.36	4.68	5.07	1.49	1.63	1.74	1.92	2.08	2.27	0.77	0.87	0.94	1.04	1.13	0.40	0.47	0.51	0.57	0.21	0.25	0.28	0.09	0.11	0.05
501-1[illegible]0	Effluent Water (lbs/day)	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	.00	.00	0.01	0.02	.00	.00	0.01	.00	.00	.00
[illegible]	Effluent Air (lbs/day)	0.39	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.12	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	.00	.00
	Air:Water Ratio	128.1	117.8	111.6	100.6	89.1	73.2	122.8	109.3	100.6	84.9	66.7	40.8	117.8	100.6	89.1	66.7	40.8	111.6	89.1	73.2	40.8	103.7	73.2	50.3	89.1	40.8	73.2
	Air Concentration (mg/cu.m)	3.90	4.21	4.39	4.73	5.05	5.47	1.62	1.79	1.89	2.07	2.25	2.45	0.84	0.95	1.01	1.13	1.23	0.44	0.51	0.55	0.61	0.23	0.27	0.30	0.10	0.12	0.05
1,001-3,300	Effluent Water (lbs/day)	.00	0.01	0.02	0.06	0.12	0.25	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	.00	0.01	0.02	0.06	.00	0.01	0.02	.00	0.01	.00
0.280	Effluent Air (lbs/day)	1.17	1.16	1.14	1.11	1.05	0.93	0.46	0.46	0.44	0.41	0.35	0.23	0.23	0.22	0.21	0.18	0.12	0.11	0.11	0.09	0.06	0.06	0.05	0.04	0.02	0.01	0.01
	Air:Water Ratio	116.4	107.1	101.4	91.4	83.5	60.7	111.7	99.3	91.4	79.3	62.7	38.5	107.1	91.4	83.5	62.7	38.5	101.4	83.5	60.7	38.5	94.2	60.7	47.4	83.5	38.5	60.7
	Air Concentration (mg/cu.m)	4.29	4.63	4.84	5.20	5.39	5.83	1.78	1.97	2.08	2.21	2.39	2.60	0.93	1.04	1.08	1.20	1.30	0.48	0.54	0.58	0.65	0.25	0.29	0.32	0.11	0.13	0.06
3,301-10,000	Effluent Water (lbs/day)	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.01	0.04	0.08	0.20	0.01	0.04	0.08	0.01	0.04	0.01
0.952	Effluent Air (lbs/day)	3.96	3.93	3.89	3.77	3.57	3.18	1.58	1.55	1.51	1.39	1.19	0.79	0.79	0.75	0.71	0.60	0.40	0.39	0.36	0.32	0.20	0.19	0.16	0.12	0.07	0.04	0.03
	Air:Water Ratio	98.6	90.8	86.0	77.7	68.9	56.5	94.6	84.3	77.7	65.4	57.4	35.5	90.8	77.7	68.9	57.4	35.5	86.0	68.9	56.5	35.5	80.0	56.5	43.6	68.9	35.5	56.5
	Air Concentration (mg/cu.m)	5.06	5.46	5.70	6.12	6.54	7.00	2.11	2.31	2.45	2.68	2.62	2.82	1.09	1.22	1.31	1.31	1.41	0.57	0.65	0.71	0.70	0.30	0.35	0.34	0.13	0.14	0.07
10,001-25,000	Effluent Water (lbs/day)	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	0.02	0.11	0.23	0.57	0.02	0.11	0.23	0.02	0.11	0.02
2.753	Effluent Air (lbs/day)	11.46	11.37	11.26	10.91	10.34	9.19	4.57	4.48	4.37	4.02	3.45	2.30	2.27	2.18	2.07	1.72	1.15	1.13	1.03	0.92	0.57	0.55	0.46	0.34	0.21	0.11	0.09
	Air:Water Ratio	98.3	90.4	85.7	77.3	68.6	56.5	94.2	83.9	77.3	65.1	51.5	31.5	90.4	77.3	68.6	51.5	31.5	85.7	68.6	56.5	31.5	79.6	56.5	38.9	69.6	31.5	56.5
	Air Concentration (mg/cu.m)	5.08	5.48	5.72	6.15	6.56	7.08	2.11	2.33	2.46	2.69	2.91	3.18	1.10	1.23	1.31	1.46	1.59	0.57	0.66	0.71	0.79	0.30	0.35	0.39	0.13	0.16	0.07
25,001-50,000	Effluent Water (lbs/day)	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	0.05	0.25	0.51	1.27	0.05	0.25	0.51	0.05	0.25	0.05
6.065	Effluent Air (lbs/day)	25.26	25.08	24.80	24.04	22.78	20.24	10.07	9.87	9.62	8.86	7.59	5.06	5.01	4.81	4.56	3.80	2.53	2.48	2.28	2.02	1.27	1.21	1.01	0.76	0.46	0.25	0.20
	Air:Water Ratio	98.1	90.2	85.5	77.1	68.4	56.3	94.1	83.7	77.1	64.9	51.4	31.5	90.2	77.1	68.4	51.4	31.5	85.5	68.4	56.3	31.5	79.5	56.3	38.8	64.4	31.5	56.3
	Air Concentration (mg/cu.m)	5.09	5.49	5.74	6.17	6.58	7.11	2.12	2.33	2.47	2.70	2.92	3.18	1.10	1.25	1.32	1.46	1.59	0.57	0.66	0.71	0.79	0.30	0.36	0.39	0.13	0.16	0.07
50,001-75,000	Effluent Water (lbs/day)	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	0.10	0.49	0.97	2.44	0.10	0.49	0.97	0.10	0.49	0.10
11.680	Effluent Air (lbs/day)	48.64	48.25	47.76	46.30	43.86	38.99	19.40	19.01	18.52	17.06	14.62	9.75	9.65	9.26	8.77	7.31	4.87	4.78	4.39	3.90	2.44	2.34	1.95	1.46	0.88	0.49	0.39
	Air:Water Ratio	98.0	90.1	85.4	77.0	68.3	56.2	94.0	83.6	77.0	64.8	51.3	31.5	90.1	77.0	68.3	51.3	31.5	85.4	68.3	56.2	31.5	79.3	56.2	38.6	68.3	31.5	56.2
	Air Concentration (mg/cu.m)	5.10	5.50	5.74	6.17	6.59	7.12	2.12	2.33	2.47	2.70	2.93	3.18	1.10	1.25	1.32	1.46	1.59	0.57	0.66	0.71	0.79	0.30	0.36	0.39	0.13	0.16	0.07
75,000-100,000	Effluent Water (lbs/day)	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	0.13	0.66	1.33	3.32	0.13	0.66	1.33	0.13	0.66	0.13
15.912	Effluent Air (lbs/day)	66.26	65.73	65.06	63.07	59.75	53.11	26.42	25.89	25.23	23.24	19.92	13.28	13.15	12.61	11.95	9.96	6.64	6.51	5.98	5.31	3.32	3.19	2.66	1.99	1.20	0.66	0.53
	Air:Water Ratio	98.1	90.1	85.3	77.0	68.2	56.2	94.0	83.6	77.0	64.8	51.3	31.5	90.1	77.0	68.2	51.3	31.5	85.3	68.2	56.2	31.5	79.3	56.2	38.7	68.2	31.5	56.2
	Air Concentration (mg/cu.m)	5.09	5.50	5.75	6.17	6.60	7.12	2.12	2.33	2.47	2.70	2.93	3.18	1.10	1.25	1.32	1.46	1.59	0.57	0.66	0.71	0.79	0.30	0.36	0.39	0.13	0.16	0.07
100,001-500,000	Effluent Water (lbs/day)	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	0.3	1.5	3.1	7.7	0.3	1.5	3.1	0.3	1.5	0.3
36.806	Effluent Air (lbs/day)	153.3	152.0	150.3	145.9	138.2	122.9	61.1	59.9	58.4	53.8	46.1	30.7	30.4	29.2	27.6	23.0	15.4	15.1	13.8	12.3	7.7	7.4	6.1	4.6	2.8	1.5	1.2
	Air:Water Ratio	98.1	90.0	85.2	76.9	68.1	56.1	93.9	83.4	76.9	64.7	51.2	31.4	90.0	76.9	68.1	51.2	31.4	85.2	68.1	56.1	31.4	79.2	56.1	38.7	68.1	31.4	56.1
	Air Concentration (mg/cu.m)	5.09	5.50	5.76	6.18	6.61	7.14	2.12	2.34	2.47	2.71	2.93	3.19	1.10	1.24	1.32	1.47	1.59	0.58	0.66	0.71	0.80	0.30	0.36	0.39	0.13	0.16	0.07
500,001-1,000,000	Effluent Water (lbs/day)	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	1.1	5.4	10.8	27.0	1.1	5.4	10.8	1.1	5.4	1.1
129.421	Effluent Air (lbs/day)	538.9	534.6	529.2	513.0	486.0	432.0	214.9	210.6	205.2	189.0	162.0	108.0	106.9	102.6	97.2	81.0	54.0	52.9	48.6	43.2	27.0	25.9	21.6	16.2	9.7	5.4	4.3
	Air:Water Ratio	98.0	89.8	85.0	76.7	67.9	55.9	93.7	83.2	76.7	64.5	51.1	31.3	89.8	76.7	67.9	51.1	31.3	85.0	67.9	55.9	31.3	79.0	55.9	38.6	67.9	31.3	55.9
	Air Concentration (mg/cu.m)	5.10	5.52	5.77	6.20	6.63	7.16	2.13	2.35	2.46	2.72	2.94	3.20	1.10	1.24	1.33	1.47	1.60	0.58	0.66	0.72	0.80	0.30	0.36	0.39	0.13	0.16	0.07
>1,000,000	Effluent Water (lbs/day)	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	4.3	21.6	43.2	108.0	4.3	21.6	43.2	4.3	21.6	4.3
517.491	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	755.7	647.8	431.8	427.5	410.3	388.7	323.9	215.9	211.6	194.3	172.7	108.0	103.6	86.4	64.8	38.9	21.6	17.3
	Air:Water Ratio	97.8	89.6	84.8	76.5	67.8	55.8	93.5	83.0	76.5	64.3	50.9	31.3	89.6	76.5	67.8	50.9	31.3	84.8	67.8	55.8	31.3	78.8	55.8	38.5	67.8	31.3	55.8
	Air Concentration (mg/cu.m)	5.11	5.53	5.78	6.21	6.64	7.17	2.13	2.35	2.49	2.72	2.95	3.20	1.11	1.24	1.33	1.47	1.60	0.58	0.66	0.72	0.80	0.30	0.36	0.39	0.13	0.16	0.07

MGD= million gallons per day
mg/cu.m =milligrams per cubic meter

Table 7-18 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED VINYL CHLORIDE

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 12.77 (mg/cu.m)	Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/l)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.05	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
101-300	Effluent Water (lbs/day)	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00
0.037	Effluent Air (lbs/day)	0.15	0.15	0.15	0.15	0.14	0.12	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
301-1,000	Effluent Water (lbs/day)	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	.00	.00	0.01	0.02	.00	.00	0.01	.00	.00	.00
0.093	Effluent Air (lbs/day)	0.39	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.12	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	.00	.00
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
1,001-3,300	Effluent Water (lbs/day)	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	.00	0.01	0.02	0.06	.00	0.01	0.02	.00	0.01	.00
0.280	Effluent Air (lbs/day)	1.17	1.16	1.14	1.11	1.05	0.93	0.46	0.46	0.44	0.41	0.35	0.23	0.23	0.22	0.21	0.18	0.12	0.11	0.11	0.09	0.06	0.06	0.05	0.04	0.02	0.01	0.01
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
3,301-10,000	Effluent Water (lbs/day)	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.01	0.04	0.08	0.20	0.01	0.04	0.08	0.01	0.04	0.01
0.952	Effluent Air (lbs/day)	3.96	3.93	3.89	3.77	3.57	3.18	1.58	1.55	1.51	1.39	1.19	0.79	0.79	0.75	0.71	0.60	0.40	0.39	0.36	0.32	0.20	0.19	0.16	0.12	0.07	0.04	0.03
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
10,001-25,000	Effluent Water (lbs/day)	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	0.02	0.11	0.23	0.57	0.02	0.11	0.23	0.02	0.11	0.02
2.753	Effluent Air (lbs/day)	11.46	11.37	11.26	10.91	10.34	9.19	4.57	4.48	4.37	4.02	3.45	2.30	2.27	2.18	2.07	1.72	1.15	1.13	1.03	0.92	0.57	0.55	0.46	0.34	0.21	0.11	0.09
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
25,001-50,000	Effluent Water (lbs/day)	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	0.05	0.25	0.51	1.27	0.05	0.25	0.51	0.05	0.25	0.05
6.060	Effluent Air (lbs/day)	25.26	25.06	24.80	24.04	22.78	20.24	10.07	9.87	9.62	8.86	7.59	5.06	5.01	4.81	4.56	3.80	2.53	2.48	2.28	2.02	1.27	1.21	1.01	0.76	0.46	0.25	0.20
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
50,001-75,000	Effluent Water (lbs/day)	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	0.10	0.49	0.97	2.44	0.10	0.49	0.97	0.10	0.49	0.10
11.680	Effluent Air (lbs/day)	48.64	48.25	47.76	46.30	43.86	38.99	19.40	19.01	18.52	17.06	14.62	9.75	9.65	9.26	8.77	7.31	4.87	4.78	4.39	3.90	2.44	2.34	1.95	1.46	0.88	0.49	0.39
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
75,000-100,000	Effluent Water (lbs/day)	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	0.13	0.66	1.33	3.32	0.13	0.66	1.33	0.13	0.66	0.13
15.912	Effluent Air (lbs/day)	66.26	65.73	65.06	63.07	59.75	53.11	26.42	25.89	25.23	23.24	19.92	13.28	13.15	12.61	11.95	9.96	6.64	6.51	5.98	5.31	3.32	3.19	2.66	1.99	1.20	0.66	0.53
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
100,001-500,000	Effluent Water (lbs/day)	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	0.3	1.5	3.1	7.7	0.3	1.5	3.1	0.3	1.5	0.3
36.806	Effluent Air (lbs/day)	153.3	152.0	150.5	145.9	138.2	122.9	61.1	59.9	58.4	53.8	46.1	30.7	30.4	29.2	27.6	23.0	15.4	15.1	13.8	12.3	7.7	7.4	6.1	4.6	2.8	1.5	1.2
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
500,001-1,000,000	Effluent Water (lbs/day)	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	1.1	5.4	10.8	27.0	1.1	5.4	10.8	1.1	5.4	1.1
129.421	Effluent Air (lbs/day)	538.9	534.6	529.2	513.0	486.0	432.0	214.9	210.6	205.2	189.0	162.0	108.0	106.9	102.6	97.2	81.0	54.0	52.9	48.6	43.2	27.0	25.9	21.6	16.2	9.7	5.4	4.3
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32
>1,000,000	Effluent Water (lbs/day)	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	4.3	21.6	43.2	108.0	4.3	21.6	43.2	4.3	21.6	4.3
517.491	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	755.7	647.8	431.8	427.5	410.3	388.7	323.9	215.9	211.6	194.3	172.7	108.0	103.6	86.4	64.8	38.9	21.6	17.3
	Air:Water Ratio	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
	Air Concentration (mg/cu.m)	40.27	39.95	39.54	38.33	36.32	32.28	16.06	15.74	15.33	14.12	12.11	8.07	7.99	7.67	7.26	6.05	4.04	3.95	3.63	3.23	2.02	1.94	1.61	1.21	0.73	0.40	0.32

MGD= million gallons per day
mg/cu.m =milligrams per cubic meter

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Table 7-17 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED 1,1-DICHLOROETHYLENE

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 19.81 (mg/cu.m)	Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/l)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100 0.013	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Effluent Air (lbs/day)	0.05	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	22.3	18.7	16.7	13.7	12.2	12.2	20.6	16.0	13.7	12.2	12.2	12.2	18.7	15.7	12.2	12.2	12.2	16.7	12.2	12.2	12.2	14.5	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	22.39	26.49	29.36	34.70	36.91	32.01	9.67	12.20	13.88	14.35	12.30	8.20	5.30	6.94	7.38	6.15	4.10	2.94	3.69	3.28	2.05	1.66	1.64	1.23	0.74	0.41	0.33
101-500 0.037	Effluent Water (lbs/day)	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00
	Effluent Air (lbs/day)	0.15	0.15	0.15	0.15	0.14	0.12	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00
	Air:Water Ratio	16.1	13.9	12.7	12.2	12.2	12.2	14.9	12.3	12.2	12.2	12.2	12.2	13.9	12.2	12.2	12.2	12.2	12.7	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	31.02	35.64	38.61	38.96	36.91	32.01	13.37	15.07	15.59	14.35	12.30	8.20	7.13	7.79	7.38	6.15	4.10	3.86	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
501-1,000 0.093	Effluent Water (lbs/day)	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	.00	.00	0.01	0.02	.00	.00	0.01	.00	.00	.00
	Effluent Air (lbs/day)	0.39	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.12	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	.00	.00
	Air:Water Ratio	13.9	12.2	12.2	12.2	12.2	12.2	13.0	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	35.93	40.60	40.19	38.96	36.91	32.01	15.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
1,001-3,300 0.280	Effluent Water (lbs/day)	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	0.23	.00	0.01	0.02	0.06	0.12	.00	0.01	0.02	0.06	.00	0.01	0.02	.00	0.01	.00
	Effluent Air (lbs/day)	1.17	1.16	1.14	1.11	1.05	0.93	0.46	0.46	0.44	0.41	0.35	0.23	0.23	0.22	0.21	0.18	0.12	0.11	0.11	0.09	0.06	0.06	0.05	0.04	0.02	0.01	0.01
	Air:Water Ratio	12.5	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	39.90	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
3,301-10,000 0.952	Effluent Water (lbs/day)	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.01	0.04	0.08	0.20	0.01	0.04	0.08	0.01	0.04	0.01
	Effluent Air (lbs/day)	3.96	3.93	3.88	3.77	3.57	3.18	1.58	1.55	1.51	1.39	1.19	0.79	0.79	0.75	0.71	0.60	0.40	0.39	0.36	0.32	0.20	0.19	0.16	0.12	0.07	0.04	0.03
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
10,001-25,000 2.753	Effluent Water (lbs/day)	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	0.02	0.11	0.23	0.57	0.02	0.11	0.23	0.02	0.11	0.02
	Effluent Air (lbs/day)	11.46	11.37	11.26	10.91	10.34	9.19	4.57	4.48	4.37	4.02	3.43	2.30	2.27	2.18	2.07	1.72	1.15	1.13	1.03	0.92	0.57	0.55	0.46	0.34	0.21	0.11	0.09
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
25,001-50,000 6.060	Effluent Water (lbs/day)	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	0.05	0.25	0.51	1.27	0.05	0.25	0.51	0.05	0.25	0.05
	Effluent Air (lbs/day)	25.26	25.05	24.80	24.04	22.78	20.24	10.07	9.87	9.62	8.86	7.59	5.06	5.01	4.81	4.56	3.80	2.53	2.48	2.28	2.02	1.27	1.21	1.01	0.76	0.46	0.25	0.20
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
50,001-75,000 11.680	Effluent Water (lbs/day)	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	0.10	0.49	0.97	2.44	0.10	0.49	0.97	0.10	0.49	0.10
	Effluent Air (lbs/day)	48.64	48.25	47.76	46.30	43.86	38.99	19.40	19.01	18.52	17.06	14.62	9.75	9.65	9.26	8.77	7.31	4.87	4.78	4.39	3.90	2.44	2.34	1.95	1.46	0.88	0.49	0.39
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
75,000-100,000 15.912	Effluent Water (lbs/day)	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	0.13	0.66	1.33	3.32	0.13	0.66	1.33	0.13	0.66	0.13
	Effluent Air (lbs/day)	66.26	65.73	65.06	63.07	59.75	53.11	26.42	25.89	25.23	23.24	19.92	13.28	13.15	12.61	11.95	9.96	6.64	6.51	5.98	5.31	3.32	3.19	2.66	1.99	1.20	0.66	0.53
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
100,001-500,000 36.806	Effluent Water (lbs/day)	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	0.3	1.5	3.1	7.7	0.3	1.5	3.1	0.3	1.5	0.3
	Effluent Air (lbs/day)	153.3	152.0	150.5	145.9	138.2	122.9	61.1	59.9	58.4	53.8	46.1	30.7	30.4	29.2	27.6	23.0	15.4	15.1	13.8	12.3	7.7	7.4	6.1	4.6	2.8	1.5	1.2
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
500,001-1,000,000 129.421	Effluent Water (lbs/day)	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	1.1	5.4	10.8	27.0	1.1	5.4	10.8	1.1	5.4	1.1
	Effluent Air (lbs/day)	538.9	534.6	529.2	513.0	486.0	432.0	214.9	210.6	205.2	189.0	162.0	108.0	106.9	102.6	97.2	81.0	54.0	52.9	48.6	43.2	27.0	25.9	21.6	16.2	9.7	5.4	4.3
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33
>1,000,000 517.495	Effluent Water (lbs/day)	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	4.3	21.6	43.2	108.0	4.3	21.6	43.2	4.3	21.6	4.3
	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	755.7	647.8	431.8	427.5	410.3	388.7	323.9	215.9	211.6	194.3	172.7	108.0	103.6	86.4	64.8	38.9	21.6	17.3
	Air:Water Ratio	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
	Air Concentration (mg/cu.m)	40.93	40.60	40.19	38.96	36.91	32.01	16.32	16.00	15.59	14.35	12.30	8.20	8.12	7.79	7.38	6.15	4.10	4.02	3.69	3.28	2.05	1.97	1.64	1.23	0.74	0.41	0.33

MGD= million gallons per day
mg/cu.m milligrams per cubic meter

Table 7-18 EFFLUENT CONCENTRATIONS AND TOTAL MASS DISCHARGED BENZENE

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 31.95 (mg/cu.m)	Influent																										
		300 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/l)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Effluent Water (lbs/day)	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	0.01	.00	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.05	0.05	0.05	0.05	0.05	0.04	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00	.00	.00	.00	.00	.00
	Air:Water Ratio	87.0	79.0	74.4	66.5	58.4	47.6	82.9	72.7	66.5	58.1	43.4	25.3	79.0	66.5	58.4	43.4	25.3	74.4	58.4	47.6	25.3	66.5	47.6	43.4	58.4	25.3	47.6
	Air Concentration (mg/cu.m)	5.74	6.27	6.59	7.15	7.71	8.41	2.40	2.60	2.86	3.17	3.46	3.96	1.25	1.43	1.54	1.73	1.98	0.66	0.77	0.84	0.99	0.35	0.42	0.38	0.15	0.20	0.08
101-500	Effluent Water (lbs/day)	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	0.03	.00	.00	.00	0.01	0.02	.00	.00	.00	0.01	.00	.00	.00	.00	.00	.00
0.037	Effluent Air (lbs/day)	0.15	0.15	0.15	0.15	0.14	0.12	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	.00	.00	.00	.00
	Air:Water Ratio	73.7	67.4	63.7	57.2	50.5	41.5	70.4	62.5	57.2	47.8	37.7	21.9	67.4	57.2	50.5	37.7	21.9	63.7	50.5	41.5	21.9	59.0	41.5	27.0	50.5	21.9	41.5
	Air Concentration (mg/cu.m)	6.70	7.35	7.70	8.51	8.92	9.69	2.85	3.15	3.52	3.86	3.98	4.57	1.47	1.66	1.78	1.99	2.30	0.77	0.89	0.97	1.14	0.41	0.48	0.54	0.18	0.25	0.10
501-1,000	Effluent Water (lbs/day)	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	0.08	.00	.00	0.01	0.02	0.04	.00	.00	0.01	0.02	.00	.00	0.01	.00	.00	.00
0.093	Effluent Air (lbs/day)	0.39	0.38	0.38	0.37	0.35	0.31	0.15	0.15	0.15	0.14	0.12	0.08	0.08	0.07	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.01	0.01	.00	.00
	Air:Water Ratio	66.0	60.6	57.4	51.7	45.7	37.5	63.2	56.2	51.7	43.4	34.2	20.4	60.6	51.7	45.7	34.2	20.4	57.4	45.7	37.5	20.4	53.3	37.5	20.6	42.7	20.4	37.5
	Air Concentration (mg/cu.m)	7.57	8.17	8.54	9.19	9.85	10.67	3.15	3.47	3.68	4.04	4.39	4.91	1.63	1.84	1.97	2.19	2.43	0.85	0.99	1.07	1.25	0.45	0.53	0.59	0.20	0.25	0.11
1,001-3,300	Effluent Water (lbs/day)	.00	0.01	0.02	0.06	0.12	0.25	.00	0.01	0.02	0.06	0.12	0.25	.00	0.01	0.02	0.06	0.12	.00	0.01	0.02	0.06	.00	0.01	0.02	.00	0.01	.00
0.288	Effluent Air (lbs/day)	1.17	1.16	1.14	1.11	1.05	0.93	0.46	0.46	0.44	0.41	0.35	0.23	0.23	0.22	0.21	0.18	0.12	0.11	0.11	0.09	0.06	0.06	0.05	0.04	0.02	0.01	0.01
	Air:Water Ratio	60.5	58.7	52.9	47.7	42.3	34.0	58.1	51.8	47.7	40.2	31.8	19.4	58.7	47.7	42.3	31.8	19.4	52.9	42.3	34.0	19.4	49.2	34.0	24.1	42.3	19.4	34.0
	Air Concentration (mg/cu.m)	8.25	8.89	9.27	9.97	10.60	11.50	3.43	3.77	3.99	4.36	4.72	5.16	1.78	1.99	2.13	2.36	2.58	0.93	1.06	1.15	1.29	0.49	0.58	0.62	0.21	0.26	0.12
3,301-10,000	Effluent Water (lbs/day)	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.79	0.01	0.04	0.08	0.20	0.40	0.01	0.04	0.08	0.20	0.01	0.04	0.08	0.01	0.04	0.01
0.952	Effluent Air (lbs/day)	3.96	3.93	3.89	3.77	3.57	3.18	1.58	1.55	1.51	1.39	1.19	0.79	0.79	0.75	0.71	0.60	0.40	0.39	0.36	0.32	0.20	0.19	0.16	0.12	0.07	0.04	0.03
	Air:Water Ratio	53.8	51.1	48.9	43.7	38.0	32.0	55.5	47.5	43.7	36.9	29.5	18.6	51.1	43.7	38.0	29.5	18.6	48.5	38.0	32.0	18.6	45.1	32.0	25.0	38.0	18.6	32.0
	Air Concentration (mg/cu.m)	9.28	9.69	10.11	10.88	11.61	12.51	3.74	4.11	4.35	4.75	5.12	5.58	1.94	2.18	2.32	2.56	2.69	1.01	1.16	1.25	1.38	0.53	0.63	0.68	0.23	0.27	0.13
10,001-25,000	Effluent Water (lbs/day)	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	2.30	0.02	0.11	0.23	0.57	1.15	0.02	0.11	0.23	0.57	0.02	0.11	0.23	0.02	0.11	0.02
2.753	Effluent Air (lbs/day)	11.46	11.37	11.26	10.91	10.34	9.19	4.57	4.48	4.37	4.02	3.45	2.30	2.27	2.18	2.07	1.72	1.15	1.13	1.05	0.92	0.57	0.55	0.46	0.34	0.21	0.11	0.09
	Air:Water Ratio	48.4	44.5	42.1	38.0	33.7	27.6	46.4	41.3	38.0	32.0	25.1	14.7	44.5	38.0	33.7	25.1	14.7	42.1	38.0	27.6	14.7	39.1	27.6	10.6	33.7	14.7	27.6
	Air Concentration (mg/cu.m)	10.32	11.15	11.68	12.51	13.36	14.50	4.29	4.73	5.00	5.47	5.90	6.01	2.25	2.50	2.67	2.99	3.40	1.16	1.19	1.45	1.70	0.61	0.73	0.81	0.27	0.34	0.15
25,001-50,000	Effluent Water (lbs/day)	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	5.06	0.05	0.25	0.51	1.27	2.53	0.05	0.25	0.51	1.27	0.05	0.25	0.51	0.05	0.25	0.05
6.058	Effluent Air (lbs/day)	25.26	25.05	24.80	24.04	22.78	20.24	10.07	9.87	9.62	8.86	7.59	5.06	5.01	4.81	4.56	3.80	2.53	2.48	2.28	2.02	1.27	1.21	1.01	0.76	0.46	0.25	0.20
	Air:Water Ratio	48.4	44.5	42.1	38.0	33.6	27.6	46.4	41.2	38.0	31.9	25.1	14.7	44.5	38.0	33.6	25.1	14.7	42.1	38.0	27.6	14.7	39.1	27.6	10.6	33.6	14.7	27.6
	Air Concentration (mg/cu.m)	10.32	11.15	11.65	12.51	13.40	14.50	4.29	4.74	5.00	5.49	5.90	6.01	2.25	2.50	2.68	2.99	3.40	1.16	1.19	1.45	1.70	0.61	0.73	0.81	0.27	0.34	0.15
50,001-75,000	Effluent Water (lbs/day)	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	9.75	0.10	0.49	0.97	2.44	4.87	0.10	0.49	0.97	2.44	0.10	0.49	0.97	0.10	0.49	0.10
11.680	Effluent Air (lbs/day)	48.64	48.25	47.76	46.30	43.86	38.99	19.40	19.01	18.52	17.06	14.62	9.75	9.65	9.26	8.77	7.31	4.87	4.78	4.39	3.90	2.44	2.34	1.95	1.46	0.88	0.49	0.39
	Air:Water Ratio	48.5	44.5	42.1	38.0	33.6	27.6	46.4	41.2	38.0	31.9	25.1	14.8	44.5	38.0	33.6	25.1	14.8	42.1	38.0	27.6	14.8	39.1	27.6	10.6	33.6	14.8	27.6
	Air Concentration (mg/cu.m)	10.30	11.15	11.68	12.51	13.40	14.50	4.29	4.74	5.00	5.49	5.90	6.76	2.25	2.50	2.68	2.99	3.38	1.16	1.19	1.45	1.69	0.61	0.73	0.81	0.27	0.34	0.15
75,000-100,000	Effluent Water (lbs/day)	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	13.28	0.13	0.66	1.33	3.32	6.64	0.13	0.66	1.33	3.32	0.13	0.66	1.33	0.13	0.66	0.13
15.912	Effluent Air (lbs/day)	66.26	65.73	65.06	63.07	59.75	53.11	26.42	25.89	25.23	23.24	19.92	13.28	13.15	12.61	11.95	9.96	6.64	6.51	5.98	5.31	3.32	3.19	2.66	1.99	1.20	0.66	0.53
	Air:Water Ratio	48.6	44.6	42.2	38.0	33.7	27.7	46.5	41.3	38.0	32.0	25.2	14.8	44.6	38.0	33.7	25.2	14.8	42.2	38.0	27.7	14.8	39.2	27.7	10.7	33.7	14.8	27.7
	Air Concentration (mg/cu.m)	10.28	11.11	11.62	12.51	13.36	14.45	4.28	4.73	5.00	5.47	5.96	6.76	2.22	2.50	2.67	2.98	3.38	1.16	1.19	1.45	1.69	0.61	0.72	0.80	0.27	0.34	0.14
100,001-500,000	Effluent Water (lbs/day)	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	30.7	0.3	1.5	3.1	7.7	15.4	0.3	1.5	3.1	7.7	0.3	1.5	3.1	0.3	1.5	0.3
36.085	Effluent Air (lbs/day)	153.3	152.0	150.5	145.9	138.2	122.9	61.1	59.9	58.4	53.8	46.1	30.7	30.4	29.2	27.6	23.0	15.4	15.1	13.8	12.3	7.7	7.4	6.1	4.6	2.8	1.5	1.2
	Air:Water Ratio	48.6	44.6	42.2	38.0	33.7	27.7	46.6	41.3	38.0	32.0	25.2	14.8	44.6	38.0	33.7	25.2	14.8	42.2	38.0	27.7	14.8	39.2	27.7	10.7	33.7	14.8	27.7
	Air Concentration (mg/cu.m)	10.28	11.11	11.62	12.51	13.36	14.45	4.27	4.73	5.00	5.47	5.96	6.76	2.22	2.50	2.67	2.98	3.38	1.16	1.19	1.45	1.69	0.61	0.72	0.80	0.27	0.34	0.14
500,001-1,000,000	Effluent Water (lbs/day)	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	108.0	1.1	5.4	10.8	27.0	54.0	1.1	5.4	10.8	27.0	1.1	5.4	10.8	1.1	5.4	1.1
129.421	Effluent Air (lbs/day)	538.9	534.6	529.2	513.0	486.0	432.0	214.9	210.6	205.2	189.0	162.0	108.0	106.9	102.6	97.2	81.0	54.0	52.9	48.6	43.2	27.0	25.9	21.6	16.2	9.7	5.4	4.3
	Air:Water Ratio	48.7	44.6	42.2	38.0	33.7	27.7	46.6	41.3	38.0	31.9	25.2	14.9	44.6	38.0	33.7	25.2	14.9	42.2	38.0	27.7	14.9	39.2	27.7	10.7	33.7	14.9	27.7
	Air Concentration (mg/cu.m)	10.25	11.11	11.62	12.51	13.36	14.45	4.27	4.73	5.00	5.49	5.96	6.72	2.22	2.50	2.67	2.98	3.36	1.16	1.19	1.45	1.68	0.61	0.72	0.80	0.27	0.34	0.14
>1,000,000	Effluent Water (lbs/day)	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	431.8	4.3	21.6	43.2	108.0	215.9	4.3	21.6	43.2	108.0	4.3	21.6	43.2	4.3	21.6	4.3
517.498	Effluent Air (lbs/day)	2,154.9	2,137.6	2,116.0	2,051.3	1,943.3	1,727.4	859.4	842.1	820.5	755.7	647.8	431.8	427.5	410.3	388.7	323.9	215.9	211.6	194.3	172.7	108.0	103.6	86.4	64.8	38.9	21.6	17.3
	Air:Water Ratio	48.7	44.6	42.2	38.0	33.6	27.6	46.6	41.3	38.0	31.9	25.2	14.9	44.6	38.0	33.6	25.2	14.9	42.2	38.0	27.6	14.9	39.2	27.6	10.7	33.6	14.9	27.6
	Air Concentration (mg/cu.m)	10.25	11.11	11.62	12.51	13.40	14.50	4.27	4.73	5.00	5.49	5.96	6.72	2.22	2.50	2.68	2.98	3.36	1.16	1.19	1.45	1.68	0.61	0.73	0.80	0.27	0.34	0.15

MGD= million gallons per day

mg/cu.m =milligrams per cubic meter

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Table 7-19. Effluent Concentrations and Total Mass Discharged 1,1,1-Trichloroethane

System Size Population Range Average Daily Flow (MGD)	Theshold Limit Value (TLV) 1908.36 (mg/cu.m)	Influent						
		500 (ug/L)			200 (ug/L)		100 (ug/L)	
		Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)	
		5	10	200	5	10	5	10
25-100	Effluent Water (lbs/day)	.00	.00	0.02	.00	.00	.00	.00
0.013	Effluent Air (lbs/day)	0.05	0.05	0.03	0.02	0.02	0.01	0.01
	Air:Water Ratio	30.4	28.5	14.0	28.0	25.5	25.5	20.9
	Air Concentration (mg/cu.m)	16.29	17.21	21.44	6.97	7.46	3.13	3.16
101-500	Effluent Water (lbs/day)	.00	.00	0.06	.00	.00	.00	.00
0.037	Effluent Air (lbs/day)	0.15	0.15	0.09	0.06	0.06	0.03	0.03
	Air:Water Ratio	24.7	22.8	14.0	22.2	19.8	19.8	16.7
	Air Concentration (mg/cu.m)	20.06	21.51	21.44	8.79	9.60	3.85	3.95
501-1,000	Effluent Water (lbs/day)	.00	0.01	0.16	.00	0.01	.00	0.01
0.093	Effluent Air (lbs/day)	0.38	0.38	0.23	0.15	0.15	0.07	0.07
	Air:Water Ratio	21.3	20.0	14.0	19.5	17.6	17.6	15.0
	Air Concentration (mg/cu.m)	23.26	24.52	21.44	10.01	10.80	4.46	4.50
1,001-3,300	Effluent Water (lbs/day)	0.01	0.02	0.47	0.01	0.02	0.01	0.02
0.280	Effluent Air (lbs/day)	1.16	1.14	0.70	0.46	0.44	0.22	0.21
	Air:Water Ratio	19.4	18.2	14.0	17.8	16.2	16.2	14
	Air Concentration (mg/cu.m)	25.53	26.94	21.44	10.96	11.74	4.90	4.95
3,301-10,000	Effluent Water (lbs/day)	0.04	0.08	1.59	0.04	0.08	0.04	0.08
0.952	Effluent Air (lbs/day)	3.93	3.89	2.38	1.55	1.51	0.75	0.71
	Air:Water Ratio	18.2	17.1	14.0	16.8	15.3	15.3	14.0
	Air Concentration (mg/cu.m)	27.22	28.68	21.44	11.62	12.43	5.22	5.27
10,001-25,000	Effluent Water (lbs/day)	0.11	0.23	4.59	0.11	0.23	0.11	0.23
2.753	Effluent Air (lbs/day)	11.37	11.26	6.89	4.48	4.37	2.18	2.07
	Air:Water Ratio	14.0	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	35.38	35.03	21.44	13.94	13.58	6.79	6.43
25,001-50,000	Effluent Water (lbs/day)	0.25	0.51	10.12	0.25	0.51	0.25	0.51
6.065	Effluent Air (lbs/day)	25.05	24.80	15.18	9.87	9.62	4.81	4.56
	Air:Water Ratio	14.1	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	35.13	35.03	21.44	13.94	13.58	6.74	6.43
50,001-75,000	Effluent Water (lbs/day)	0.49	0.97	19.49	0.49	0.97	0.49	0.97
11.680	Effluent Air (lbs/day)	48.25	47.76	29.24	19.01	18.52	9.26	8.77
	Air:Water Ratio	14.3	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	34.64	35.03	21.44	13.94	13.58	6.65	6.43
75,000-100,000	Effluent Water (lbs/day)	0.66	1.33	26.56	0.66	1.33	0.66	1.33
15.912	Effluent Air (lbs/day)	65.73	65.06	39.84	25.89	25.23	12.61	11.95
	Air:Water Ratio	14.5	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	34.16	35.03	21.44	13.94	13.58	6.56	6.43
100,001-500,000	Effluent Water (lbs/day)	1.5	3.1	61.4	1.5	3.1	1.5	3.1
36.806	Effluent Air (lbs/day)	152.0	150.5	92.1	59.9	58.4	29.2	27.6
	Air:Water Ratio	14.6	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	33.93	35.03	21.44	13.94	13.58	6.51	6.43
500,001-1,000,000	Effluent Water (lbs/day)	5.4	10.8	216.0	5.4	10.8	5.4	10.8
129.421	Effluent Air (lbs/day)	534.6	529.2	324.0	210.6	205.2	102.6	97.2
	Air:Water Ratio	14.8	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	33.47	35.03	21.44	13.94	13.58	6.42	6.43
>1,000,000	Effluent Water (lbs/day)	21.6	43.2	863.7	21.6	43.2	21.6	43.2
517.491	Effluent Air (lbs/day)	2,137.6	2,116.0	1,295.5	842.1	820.5	410.3	388.7
	Air:Water Ratio	14.9	14.0	14.0	14.0	14.0	14.0	14.0
	Air Concentration (mg/cu.m)	33.25	35.03	21.44	13.94	13.58	6.38	6.43

MGD= million gallons per day
mg/cu.m =milligrams per cubic meter

Table 7-20. Effluent Concentrations and Total Mass Discharged p-Dichlorobenzene

System Size Population Range Average Daily Flow (MGD)	Threshold Limit Value (TLV) 450.62 (mg/cu. m)	Influent				
		1000 (ug/l)			500 (ug/L)	
		Effluent (ug/L)			Effluent (ug/L)	
		5	10	750	5	10
25-100	Effluent Water (lbs/day)	0.001	0.001	0.081	0.001	0.001
0.013	Effluent Air (lbs/day)	0.11	0.11	0.03	0.05	0.05
	Air:Water Ratio	137.5	131.6	20.8	131.6	124.3
	Effluent Air (mg/cu. m)	7.24	7.52	12.02	3.76	3.94
101-500	Effluent Water (lbs/day)	0.002	0.003	0.232	0.002	0.003
0.037	Effluent Air (lbs/day)	0.31	0.31	0.08	0.15	0.15
	Air:Water Ratio	119.4	114.5	18.4	114.5	108.5
	Effluent Air (mg/cu. m)	8.33	8.65	13.59	4.32	4.52
501-1,000	Effluent Water (lbs/day)	0.004	0.008	0.582	0.004	0.008
0.093	Effluent Air (lbs/day)	0.77	0.77	0.19	0.38	0.38
	Air:Water Ratio	109.0	104.7	17.3	104.7	99.3
	Effluent Air (mg/cu. m)	9.13	9.46	14.45	4.73	4.93
1,001-3,300	Effluent Water (lbs/day)	0.012	0.023	1.752	0.012	0.023
0.280	Effluent Air (lbs/day)	2.32	2.31	0.58	1.16	1.14
	Air:Water Ratio	98.8	94.9	16.6	94.9	89.9
	Effluent Air (mg/cu. m)	10.07	10.43	15.06	5.22	5.45
3,301-10,000	Effluent Water (lbs/day)	0.040	0.079	5.958	0.040	0.079
0.952	Effluent Air (lbs/day)	7.90	7.86	1.99	3.93	3.89
	Air:Water Ratio	82.9	79.6	16.1	79.6	75.5
	Effluent Air (mg/cu. m)	12.00	12.44	15.53	6.22	6.49
10,001-25,000	Effluent Water (lbs/day)	0.115	0.230	17.23	0.115	0.230
2.753	Effluent Air (lbs/day)	22.86	22.74	5.74	11.37	11.26
	Air:Water Ratio	82.5	79.2	13.2	79.2	75.1
	Effluent Air (mg/cu. m)	12.06	12.50	18.94	6.25	6.52
25,001-50,000	Effluent Water (lbs/day)	0.25	0.51	37.96	0.25	0.51
6.065	Effluent Air (lbs/day)	50.36	50.11	12.65	25.05	24.80
	Air:Water Ratio	82.5	79.2	13.2	79.2	75.1
	Effluent Air (mg/cu. m)	12.06	12.50	18.94	6.25	6.52
50,001-75,000	Effluent Water (lbs/day)	0.49	0.97	73.10	0.49	0.97
11.680	Effluent Air (lbs/day)	96.98	96.49	24.37	48.25	47.76
	Air:Water Ratio	82.5	79.2	13.2	79.2	75.1
	Effluent Air (mg/cu. m)	12.06	12.50	18.94	6.25	6.52
75,000-100,000	Effluent Water (lbs/day)	0.66	1.33	99.59	0.66	1.33
15.912	Effluent Air (lbs/day)	132.1	131.5	33.2	65.7	65.1
	Air:Water Ratio	82.5	79.2	13.2	79.2	75.1
	Effluent Air (mg/cu. m)	12.06	12.50	18.94	6.25	6.52
100,001-500,000	Effluent Water (lbs/day)	1.54	3.07	230.36	1.54	3.07
36.806	Effluent Air (lbs/day)	305.6	304.1	76.8	152.0	150.5
	Air:Water Ratio	82.5	79.2	13.2	79.2	75.0
	Effluent Air (mg/cu. m)	12.06	12.30	18.94	6.25	6.53
500,001-1,000,000	Effluent Water (lbs/day)	5.40	10.80	810.01	5.40	10.80
129.421	Effluent Air (lbs/day)	1,074.6	1,069.2	270.0	534.6	529.2
	Air:Water Ratio	82.4	79.1	13.2	79.1	74.9
	Effluent Air (mg/cu. m)	12.08	12.52	18.94	6.26	6.54
>1,000,000	Effluent Water (lbs/day)	21.59	43.18	3238.85	21.59	43.18
517.491	Effluent Air (lbs/day)	4,297	4,275	1,080	2,138	2,116
	Air:Water Ratio	82.3	78.9	13.2	78.9	74.8
	Effluent Air (mg/cu. m)	12.09	12.55	18.94	6.27	6.55

MGD= million gallons per day
mg/cu.m =milligrams per cubic meter

Table 7-21. ISC Dispersion Model Output

System Size = 0.093 MGD Discharge = 5.42 x 10^{-3} g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	0.003	0.0008	0.00008	0.00001	0.000002
	3.0	0.001	0.0004	0.00004	0.000006	0.000001
Unstable	1.5	0.005	0.002	0.0003	0.00007	0.00002
	5.0	0.002	0.0005	0.00009	0.00002	0.000005
Slightly Unstable	1.5	0.011	0.003	0.0006	0.0002	0.00005
	10.0	0.002	0.0005	0.0001	0.00003	0.000008
Neutral	2.0	0.016	0.006	0.001	0.0004	0.0001
	15.0	0.002	0.0008	0.0002	0.00005	0.00002
Slightly Stable	1.5	0.031	0.013	0.003	0.001	0.0004
	5.0	0.010	0.004	0.001	0.0003	0.0001

Table 7-22. ISC Dispersion Model Output

System Size = 2.753 MGD

Discharge = 1.16 x 10^{-1} g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	0.042	0.014	0.001	0.0003	0.00006
	3.0	0.022	0.007	0.001	0.0001	0.00003
Unstable	1.5	0.043	0.025	0.006	0.001	0.0003
	5.0	0.018	0.008	0.001	0.0004	0.0001
Slightly Unstable	1.5	0.057	0.045	0.011	0.003	0.001
	10.0	0.011	0.007	0.001	0.0004	0.0001
Neutral	2.0	0.014	0.045	0.020	0.007	0.003
	15.0	0.003	0.007	0.003	0.001	0.0003
Slightly Stable	1.5	0.004	0.050	0.041	0.017	0.006
	5.0	0.001	0.017	0.013	0.006	0.001

Table 7-23. ISC Dispersion Model Output

System Size = 6.065 MGD   Discharge = 2.40×10^{-1} g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	0.087	0.029	0.003	0.0006	0.0001
	3.0	0.046	0.015	0.002	0.0003	0.00006
Unstable	1.5	0.113	0.052	0.012	0.003	0.006
	5.0	0.038	0.017	0.003	0.0009	0.0002
Slightly Unstable	1.5	0.119	0.093	0.023	0.006	0.002
	10.0	0.023	0.014	0.003	0.0009	0.0003
Neutral	2.0	0.029	0.093	0.041	0.014	0.006
	15.0	0.006	0.014	0.006	0.002	0.0006
Slightly Stable	1.5	0.009	0.104	0.084	0.035	0.012
	5.0	0.003	0.035	0.026	0.012	0.003

Table 7-24. ISC Dispersion Model Output

System Size = 11.680 MGD   Discharge = 4.21 x 10^{-1} g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	0.153	0.051	0.005	0.001	0.0002
	3.0	0.082	0.026	0.004	0.0005	0.0001
Unstable	1.5	0.199	0.092	0.020	0.005	0.001
	5.0	0.066	0.031	0.005	0.002	0.0004
Slightly Unstable	1.5	0.209	0.163	0.041	0.010	0.004
	10.0	0.041	0.026	0.005	0.002	0.0005
Neutral	2.0	0.051	0.163	0.071	0.026	0.010
	15.0	0.010	0.026	0.010	0.004	0.001
Slightly Stable	1.5	0.015	0.184	0.148	0.061	0.020
	5.0	0.005	0.061	0.046	0.020	0.005

Table 7-25. ISC Dispersion Model Output

System Size = 15.912 MGD Discharge = 5.29×10^{-1} g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	0.192	0.064	0.006	0.001	0.0003
	3.0	0.102	0.032	0.004	0.0006	0.0001
Unstable	1.5	0.250	0.115	0.026	0.006	0.001
	5.0	0.083	0.038	0.006	0.002	0.0004
Slightly Unstable	1.5	0.262	0.205	0.051	0.013	0.004
	10.0	0.051	0.032	0.006	0.002	0.0006
Neutral	2.0	0.064	0.205	0.090	0.032	0.013
	15.0	0.013	0.032	0.013	0.004	0.001
Slightly Stable	1.5	0.019	0.230	0.186	0.077	0.026
	5.0	0.006	0.077	0.058	0.026	0.006

Table 7-26. ISC Dispersion Model Output

System Size = 36.806 MGD Discharge = 1.12 g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	0.408	0.136	0.014	0.003	0.0005
	3.0	0.218	0.068	0.010	0.001	0.0003
Unstable	1.5	0.530	0.245	0.054	0.014	0.003
	5.0	0.177	0.082	0.014	0.004	0.001
Slightly Unstable	1.5	0.558	0.435	0.109	0.027	0.010
	10.0	0.109	0.068	0.014	0.004	0.001
Neutral	2.0	0.136	0.435	0.190	0.068	0.027
	15.0	0.027	0.068	0.027	0.010	0.003
Slightly Stable	1.5	0.041	0.490	0.394	0.163	0.054
	5.0	0.014	0.163	0.122	0.054	0.014

Table 7-27. ISC Dispersion Model Output

System Size = 129.421 MGD Discharge = 3.74 g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	1.359	0.453	0.045	0.009	0.002
	3.0	0.725	0.227	0.032	0.004	0.0009
Unstable	1.5	1.767	0.815	0.181	0.045	0.009
	5.0	0.589	0.272	0.045	0.014	0.003
Slightly Unstable	1.5	1.857	1.450	0.362	0.091	0.032
	10.0	0.362	0.227	0.045	0.014	0.005
Neutral	2.0	0.453	1.450	0.634	0.227	0.091
	15.0	0.091	0.227	0.091	0.032	0.009
Slightly Stable	1.5	0.136	1.631	1.314	0.544	0.181
	5.0	0.045	0.544	0.408	0.181	0.045

Table 7-28. ISC Dispersion Model Output

System Size = 517.491 MGD Discharge = 14.14 g/sec

Meteorological Conditions		Concentrations (mg/m^3) at Downwind Distance (km)				
Stability	Wind Speed (m/s)	0.1	0.2	0.5	1.0	2.0
Very Stable	1.5	5.136	1.712	0.171	0.034	0.007
	3.0	2.739	0.856	0.120	0.015	0.003
Unstable	1.5	6.677	3.082	0.685	0.171	0.034
	5.0	2.226	1.027	0.171	0.051	0.012
Slightly Unstable	1.5	7.019	5.478	1.370	0.342	0.120
	10.0	1.370	0.856	0.171	0.051	0.017
Neutral	2.0	1.712	5.478	2.400	0.856	0.342
	15.0	0.342	0.856	0.342	0.120	0.034
Slightly Stable	1.5	0.514	6.163	4.965	2.054	0.685
	5.0	0.171	2.054	1.541	0.685	0.171

Table 7-29. Estimated Costs for Removing Trichloroethylene by Packed Tower Aeration Including Off-Gas Treatment

System Size Population Range Average Daily Flow (MGD)	Influent = 500 ug/L Effluent = 1 ug/L	Cost Without Off-Gas Treatment	Additional Cost For Off-Gas Treatment	Total Cost Including Off-Gas Treatment
25-100 0.013	Total Capital Cost (K$)	58	11	69
	O&M Cost (K$/year)	0.9	1.0	2.0
	Total Production Cost (cents/1,000 gal)	183.5	53.9	237.4
101-500 0.037	Total Capital Cost (K$)	76	39	115
	O&M Cost (K$/year)	1.6	3.0	4.6
	Total Production Cost (cents/1,000 gal)	87.2	60.7	147.9
501-1,000 0.093	Total Capital Cost (K$)	102	59	161
	O&M Cost (K$/year)	3.2	6.4	9.6
	Total Production Cost (cents/1,000 gal)	49.7	42.2	91.9
1,001-3,300 0.280	Total Capital Cost (K$)	159	64	223
	O&M Cost (K$/year)	7.5	11.1	18.6
	Total Production Cost (cents/1,000 gal)	28.2	19.2	47.4
3,301-10,000 0.952	Total Capital Cost (K$)	314	118	432
	O&M Cost (K$/year)	22.0	36.0	58.0
	Total Production Cost (cents/1,000 gal)	18.5	14.9	33.4
10,001-25,000 2.753	Total Capital Cost (K$)	621	237	858
	O&M Cost (K$/year)	62	92	154
	Total Production Cost (cents/1,000 gal)	135.0	12.3	147.3
25,001-50,000 6.065	Total Capital Cost (K$)	1,248	447	1,695
	O&M Cost (K$/year)	135	206	341
	Total Production Cost (cents/1,000 gal)	13.6	12.0	25.6
50,001-75,000 11.680	Total Capital Cost (K$)	2,153	891	3,044
	O&M Cost (K$/year)	247	406	653
	Total Production Cost (cents/1,000 gal)	12.6	12.3	24.9
75,000-100,000 15.912	Total Capital Cost (K$)	2,751	1,043	3,794
	O&M Cost (K$/year)	331	545	876
	Total Production Cost (cents/1,000 gal)	12.0	11.8	23.8
100,001-500,000 36.806	Total Capital Cost (K$)	5,854	2,235	8,089
	O&M Cost (K$/year)	737	1,256	1,993
	Total Production Cost (cents/1,000 gal)	11.3	11.6	22.9
500,001-1,000,000 129.421	Total Capital Cost (K$)	19,419	7,597	27,016
	O&M Cost (K$/year)	2,561	4,459	7,020
	Total Production Cost (cents/1,000 gal)	10.9	11.6	22.5
>1,000,000 517.491	Total Capital Cost (K$)	73,188	29,198	102,386
	O&M Cost (K$/year)	10,097	17,950	28,047
	Total Production Cost (cents/1,000 gal)	10.5	11.6	22.1

MGD= million gallons per day

Table 7-30. Cost Indices for Determining Capital Costs

Cost Category	Index	August 1983	Cost Factors* Gravity Contactors	Cost Factors* Regeneration Furnace
Excavation and Site Work	ENR† Skilled Labor	365.8	0.01	0.00
Manufacturing Equipment	BLS** 11-4	308.3	0.14	0.53
Concrete	BLS 13-2	317.2	0.05	0.00
Steel	BLS 10-17	351.4	0.03	0.00
Labor	ENR Skilled Labor	365.8	0.20	0.28
Pipes and Valves	BLS 11-49-01	323.1	0.41	0.02
Electrical and Instrumentation	BLS 11-7	241.2	0.02	0.01
Housing	ENR BCI	343.4	0.14	0.16
Weighted Construction Cost Index (CCI)			331.8	329.6

* Cost Factors = Fraction of total.
† ENR = Engineering News Record.
** BLS = Bureau of Labor Statistics.

Table 7-31. GAC Contactor Design Parameters, Capital Costs, and O&M Costs

System Size Population Range Average Daily Flow (MGD)	Area of Contactor (sq ft)	Number of Units	Volume of Each Unit (cubic ft)	Backwash Pump Size (gpm)	Number of Backwash Pumps	Total Capital Cost ($)	Amortized* Total Capital Cost ($/Year)	Operations & Maintenance Cost ($/Year)
25-100 0.013	4.9	1	15	NA	NA	13,300	1,780	640
101-500 0.037	19.6	1	59	NA	NA	23,900	3,200	1,870
501-1,000 0.093	19.6	2	59	NA	NA	47,700	6,390	3,730
1,001-3,300 0.280	64.0	1	318	NA	NA	77,600	10,400	6,580
3,301-10,000 0.952	64.0	3	318	NA	NA	235,700	31,600	19,730
10,001-25,000 2.753	160.0	2	1,280	2,880	1	815,000	109,100	16,100
25,001-50,000 6.065	176.0	4	1,408	3,170	1	1,553,000	208,000	34,500
50,001-75,000 11.680	340.0	4	2,720	6,120	2	2,234,000	299,000	57,200
75,001-100,000 15.912	460.0	4	3,680	8,280	2	2,538,000	340,000	72,100
100,001-500,000 36.806	535.0	8	4,280	9,630	3	5,137,000	688,000	162,000
500,001-1,000,000 129.421	940.0	16	7,520	16,920	4	12,232,000	1,638,000	501,000
>1,000,000 517.491	1,000.0	60	8,000	18,000	16	47,439,000	6,351,000	1,971,000

MGD=million gallons per day
NA Not Applicable
* Amortized at 12 percent for 20 years.

Table 7-32. Assumptions Used to Update Adsorber O&M Costs to August 1983

Cost Category	Cost Assumption
Energy	$ 0.07 per kwhr
Labor	$ 4.55 per hour (size categories <150,000 gpd) $11.00 per hour (size categories >150,000 gpd)

Table 7-33. Carbon Usage Rates--Trichloroethylene
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)					
		1	50	10	25	50	100
Trichloroethylene	500	.310	.256	.238	.218	.205	.193
	200	.158	.143	.137	.130	.125	.121
	100	.116	.107	.104	.100	.097	
	50	.091	.086	.084	.081		
	25	.075	.071	.070			
	10	.061	.058				
	5	.053					

Notes:

1. Predictor Equation: Carbon Usage = 83.95 + 3.38 (log effluent) - 26.95 (log influent)

2. r^2 = correlation coefficient = 0.90

3. Influent and Effluent Concentration = ug/L

4. Throughput = $\frac{1{,}000\ \text{m}^3\ \text{water}}{\text{m}^3\ \text{carbon}}$

Where:

$$\text{Carbon Usage (lbs carbon/1,000 gal water)} = \frac{1}{.288^{*} \times \left(\frac{1{,}000\ \text{m}^3\ \text{water}}{\text{m}^3\ \text{carbon}}\right)}$$

$$^{*}\text{Conversion Factor} = \frac{264.17205\ \text{gal/m}^3}{35.314667\ \text{ft}^3/\text{m}^3 \times 26\ \text{lbs GAC/ft}^3} = .288$$

Table 7-34. Carbon Usage Rates—Tetrachloroethylene
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)						
		1	5	10	15	25	50	100
Tetrachloroethylene	500	.131	.096	.086	.081	.076	.069	.064
	200	.056	.048	.046	.044	.043	.041	.039
	100	.039	.035	.034	.033	.032	.031	
	50	.030	.028	.027	.026	.026		
	25	.024	.023	.022	.022			
	10	.020	.018					
	5	.017						

Notes:

1. Predictor Equation: Carbon Usage = 266.76 + 13.84 (log effluent) - 88.98 (log influent)

2. r^2 = correlation coefficient = 0.88

3. Influent and Effluent Concentration = ug/L

4. Throughput $= \dfrac{1{,}000\ m^3\ \text{water}}{m^3\ \text{carbon}}$

Where:

$$\text{Carbon Usage (lbs carbon/1,000 gal water)} = \frac{1}{.288^{*} \times \left(\dfrac{1{,}000\ m^3\ \text{water}}{m^3\ \text{carbon}}\right)}$$

$$^{*}\text{Conversion Factor} = \frac{264.17205\ \text{gal}/m^3}{35.314667\ ft^3/m^3 \times 26\ \text{lbs GAC}/ft^3} = .288$$

Table 7-35. Carbon Usage Rates—Carbon Tetrachloride
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)					
		1	5	10	25	50	100
Carbon Tetrachloride	500	.470	.375	.345	.312	.291	.272
	200	.379	.315	.293	.269	.253	.239
	100	.331	.281	.263	.244	.231	
	50	.293	.253	.239	.223		
	25	.263	.231	.219			
	10	.232	.206				
	5	.213					

Notes:

1. Predictor Equation: Carbon Usage = 19.40 + 2.68 (log effluent) - 4.45 (log influent)

2. r^2 = correlation coefficient = 0.88

3. Influent and Effluent Concentration = ug/L

4. Throughput $= \dfrac{1{,}000\ \text{m}^3\ \text{water}}{\text{m}^3\ \text{carbon}}$

Where:

$$\text{Carbon Usage (lbs carbon/1,000 gal water)} = \frac{1}{.288^{*} \times \left(\dfrac{1{,}000\ \text{m}^3\ \text{water}}{\text{m}^3\ \text{carbon}}\right)}$$

$$^{*}\text{Conversion Factor} = \frac{264.17205\ \text{gal/m}^3}{35.314667\ \text{ft}^3/\text{m}^3 \times 26\ \text{lbs GAC/ft}^3} = .288$$

Table 7-36. Carbon Usage Rates—1,2-Dichloroethane
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)					
		1	5	10	25	50	100
1,2-Dichloroethane	500	.961	.740	.674	.602	.557	.519
	200	.762	.616	.569	.517	.484	.455
	100	.659	.547	.510	.468	.440	
	50	.580	.492	.462	.427		
	25	.518	.447	.421			
	10	.454	.398				
	5	.416					

Notes:

1. Predictor Equation: Carbon Usage = 10.01 + 1.54 (log effluent) - 2.37 (log influent)

2. r^2 = correlation coefficient = 0.88

3. Influent and Effluent Concentration = ug/L

4. Throughput $= \frac{1{,}000 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ carbon}}$

Where:

$$\text{Carbon Usage (lbs carbon/1,000 gal water)} = \frac{1}{.288^{*} \times \left(\frac{1{,}000 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ carbon}}\right)}$$

$$^{*}\text{Conversion Factor} = \frac{264.17205 \text{ gal/m}^3}{35.314667 \text{ ft}^3/\text{m}^3 \times 26 \text{ lbs GAC/ft}^3} = .288$$

Table 7-37. Carbon Usage Rates—1,1-Dichloroethylene
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)					
		1	5	10	25	50	100
1,2-Dichloroethylene	500	.361	.271	.245	.217	.200	.185
	200	.142	.126	.120	.113	.108	.104
	100	.098	.090	.087	.083	.080	
	50	.074	.070	.068	.065		
	25	.060	.057	.056			
	10	.048	.046				
	5	.041					

Notes:

1. Predictor Equation: Carbon Usage = 109.65 + 4.55 (log effluent) - 37.06 (log influent)

2. r^2 = correlation coefficient = 0.86

3. Influent and Effluent Concentration = ug/L

4. Throughput $= \dfrac{1{,}000 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ carbon}}$

Where:

$$\text{Carbon Usage (lbs carbon/1,000 gal water)} = \frac{1}{.288^{*} \times \left(\dfrac{1{,}000 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ carbon}}\right)}$$

$$^{*}\text{Conversion Factor} = \frac{264.17205 \text{ gal/m}^3}{35.314667 \text{ ft}^3/\text{m}^3 \times 26 \text{ lbs GAC/ft}^3} = .288$$

Table 7-38. Carbon Usage Rates—1,1,1-Trichloroethane
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)		
		5	10	200
1,1,1-Trichloroethane	500	.967	.807	.470
	200	.166	.161	
	100	.102	.100	

Notes:

1. Predictor Equation: Carbon Usage = 119.07 + 2.37 (log effluent) - 43.40 (log influent)

2. r^2 = correlation coefficient = 0.76

3. Influent and Effluent Concentration = ug/L

4. Throughput $= \frac{1{,}000 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ carbon}}$

Where:

$$\text{Carbon Usage (lbs carbon/1,000 gal water)} = \frac{1}{.288^* \times \left(\frac{1{,}000 \text{ m}^3 \text{ water}}{\text{m}^3 \text{ carbon}}\right)}$$

$$^*\text{Conversion Factor} = \frac{264.17205 \text{ gal/m}^3}{35.314667 \text{ ft}^3/\text{m}^3 \times 26 \text{ lbs GAC/ft}^3} = .288$$

Table 7-39. Carbon Usage Rates—Benzene
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)					
		1	5	10	25	50	100
Benzene	500	3.240	1.370	.939	.560	.367	.226
	200	1.292	.540	.364	.206	.122	.057
	100	.643	.263	.172	.088	.041	
	50	.318	.125	.077	.029		
	25	.156	.055	.029			
	10	.058	.014				
	5	.026					

Freundlich Equation: $\log M = \log (C_{in} - C_{eff}) - \log K - 1/n \log C_{eff}$

$K = 50$
$1/n = .53$
$C_{in} = \text{mg/L}$
$C_{eff} = \text{mg/L}$
$M = \text{g/L}$

$$M \times 8.345^{*} = \frac{\text{lbs carbon}}{\text{1,000 gal water}}$$

$$^{*}\text{Conversion Factor} = \frac{g}{L} \times 8.345 \times 10^{-3} \frac{\text{lb/gal}}{\text{g/L}} \times 1{,}000 = 8.345$$

Table 7-40. Carbon Usage Rates--p-Dichlorobenzene
lbs GAC/1,000 Gallons Water Treated

Volatile Organic Chemical	Influent Concentration (ug/L)	Effluent Concentration (ug/L)		
		5	10	750
p-Dichlorobenzene	1,000	.570	.374	.007
	500	.283	.185	

Freundlich Equation: $\log M = \log (C_{in} - C_{eff}) - \log K - 1/n \log C_{eff}$

$K = 350$
$1/n = 0.6$
$C_{in} = \text{mg/L}$
$C_{eff} = \text{mg/L}$
$M = \text{g/L}$

$$M \times 8.345^{*} = \frac{\text{lbs carbon}}{\text{1,000 gal water}}$$

$$^{*}\text{Conversion Factor} = \frac{g}{L} \times 8.345 \times 10^{-3} \frac{\text{lb/gal}}{\text{g/L}} \times 1{,}000 = 8.345$$

Table 7-41 ESTIMATED COST FOR REMOVING TRICHLOROETHYLENE BY GRANULAR ACTIVATED CARBON ADSORPTION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
0.013	O&M Cost (K$/year)	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8
	Total Production Cost (cents/1,000 gal)	74.6	70.4	68.3	66.2	66.2	64.1	62.0	62.0	59.9	59.9	59.9	59.9	59.9	57.8	57.8	57.8	57.8	57.8	57.8	55.6	55.6	55.6	55.6	55.6	55.6	55.6	53.5
101-500	Total Capital Cost (K$)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
0.037	O&M Cost (K$/year)	5.0	4.5	4.3	4.1	3.9	3.8	3.5	3.3	3.3	3.2	3.1	3.1	3.0	3.0	2.9	2.9	2.9	2.8	2.7	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.4
	Total Production Cost (cents/1,000 gal)	60.8	57.1	55.6	54.2	52.7	51.9	49.7	48.2	48.2	47.5	46.7	46.7	46.0	46.0	45.3	45.3	45.3	44.5	43.8	43.8	43.8	43.0	43.0	43.0	42.3	42.3	41.6
501-1,000	Total Capital Cost (K$)	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
0.093	O&M Cost (K$/year)	11.6	10.2	9.8	9.3	8.9	8.6	7.8	7.4	7.2	7.0	6.9	6.8	6.7	6.5	6.4	6.3	6.2	6.0	5.9	5.9	5.8	5.6	5.5	5.5	5.3	5.2	5.1
	Total Production Cost (cents/1,000 gal)	53.1	49.0	47.8	46.3	45.2	44.5	41.9	40.7	40.1	39.6	39.3	39.0	38.7	38.1	37.8	37.5	37.2	36.6	36.3	36.3	36.0	35.4	35.1	35.1	34.5	34.3	34.0
1,001-3,300	Total Capital Cost (K$)	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78
0.280	O&M Cost (K$/year)	30.3	26.2	24.8	23.3	22.3	21.4	18.7	17.5	17.1	16.5	16.2	15.9	15.5	14.8	14.6	14.2	14.0	13.6	13.2	13.0	12.8	12.3	12.0	11.9	11.3	11.0	10.6
	Total Production Cost (cents/1,000 gal)	39.9	35.9	34.5	33.0	32.0	31.2	28.5	27.5	26.9	26.4	26.1	25.8	25.4	24.7	24.5	24.1	23.9	23.5	23.1	22.9	22.7	22.3	22.0	21.9	21.3	21.0	20.6
3,301-10,000	Total Capital Cost (K$)	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
0.952	O&M Cost (K$/year)	93.6	86.4	81.8	76.5	73.2	70.0	60.9	57.0	55.4	53.6	52.3	51.3	50.0	47.6	46.8	45.8	45.0	43.4	42.1	41.6	40.8	39.5	38.2	38.0	35.6	34.8	33.5
	Total Production Cost (cents/1,000 gal)	38.3	34.0	32.6	31.1	30.2	29.2	26.6	25.5	25.0	24.5	24.1	23.9	23.5	22.8	22.6	22.3	22.0	21.6	21.2	21.1	20.8	20.4	20.1	20.0	19.3	19.1	18.7
10,001-25,000	Total Capital Cost (K$)	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815
2.753	O&M Cost (K$/year)	171.9	144.7	135.7	125.6	119.1	115.1	95.5	87.9	84.9	81.4	78.9	76.9	74.4	69.9	68.4	66.3	89.2	86.7	80.9	79.4	77.1	72.6	69.6	66.9	62.1	59.8	56.0
	Total Production Cost (cents/1,000 gal)	28.0	25.3	24.4	23.4	22.7	22.1	20.4	19.6	19.3	19.0	18.7	18.5	18.5	17.8	17.7	17.5	19.7	19.3	18.9	18.8	18.5	18.1	17.8	17.7	17.0	16.8	16.4
25,001-50,000	Total Capital Cost (K$)	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553
6.065	O&M Cost (K$/year)	377.6	317.9	297.9	275.8	261.4	248.1	209.4	192.8	186.1	178.4	172.9	166.4	162.9	152.9	149.6	145.2	141.9	135.2	129.7	127.5	124.2	117.5	113.1	112.0	102.0	98.7	93.2
	Total Production Cost (cents/1,000 gal)	26.4	23.8	22.8	21.9	21.2	20.6	18.9	18.1	17.8	17.5	17.2	17.0	16.8	16.3	16.1	16.0	15.8	15.5	15.3	15.2	15.0	14.7	14.5	14.5	14.0	13.9	13.6
50,001-75,000	Total Capital Cost (K$)	4,797	4,591	4,517	4,450	4,372	4,316	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234
11.680	O&M Cost (K$/year)	296.8	260.4	248.1	257.4	247.0	237.2	394.0	362.0	349.2	334.5	323.7	315.1	304.5	285.3	278.9	270.4	264.0	251.2	240.5	236.3	229.9	217.1	208.5	206.4	187.2	180.8	170.2
	Total Production Cost (cents/1,000 gal)	22.0	20.5	20.0	19.9	19.5	19.1	16.5	15.5	15.2	14.9	14.6	14.4	14.2	13.7	13.6	13.4	13.2	12.9	12.7	12.6	12.4	12.1	11.9	11.9	11.4	11.3	11.0
75,000-100,000	Total Capital Cost (K$)	5,474	5,238	5,152	5,034	4,987	4,925	4,722	4,629	4,590	4,545	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538	2,538
15.912	O&M Cost (K$/year)	380.0	337.4	321.2	303.1	291.1	280.1	270.1	253.6	246.9	239.1	435.1	425.5	409.0	382.8	374.1	362.9	353.8	336.4	321.8	316.0	307.3	289.9	278.5	275.4	249.2	240.5	226.0
	Total Production Cost (cents/1,000 gal)	19.2	17.9	17.4	16.9	16.5	16.2	15.5	15.0	14.8	14.6	13.3	13.1	12.9	12.4	12.3	12.1	11.9	11.6	11.4	11.3	11.1	10.8	10.6	10.6	10.1	10.0	9.7
100,001-500,000	Total Capital Cost (K$)	9,380	9,038	8,915	8,772	8,675	8,583	8,293	8,158	8,102	8,034	7,985	7,944	7,853	7,797	7,764	7,719	7,685	7,614	7,584	7,529	7,491	7,415	7,359	7,345	7,218	7,170	5,137
36.806	O&M Cost (K$/year)	809.5	710.2	676.6	638.8	614.1	591.0	522.8	493.0	480.9	466.8	456.6	448.5	438.2	419.6	413.4	405.0	398.8	386.1	375.4	371.2	364.7	351.7	346.9	344.3	341.4	333.6	318.0
	Total Production Cost (cents/1,000 gal)	15.4	14.3	13.9	13.5	13.2	13.0	12.2	11.8	11.7	11.5	11.4	11.3	11.1	10.9	10.8	10.7	10.6	10.5	10.3	10.3	10.2	10.0	10.1	10.0	9.7	9.6	9.0
500,001-1,000,000	Total Capital Cost (K$)	23,110	19,007	18,793	18,545	18,377	18,217	17,713	17,479	17,381	17,264	17,170	17,108	17,018	16,851	16,794	16,716	16,657	16,534	16,429	16,386	16,320	16,184	16,090	16,066	15,841	15,762	15,625
129.421	O&M Cost (K$/year)	2,621.9	2,146.2	2,044.1	1,929.6	1,804.6	1,784.8	1,579.4	1,488.4	1,452.1	1,409.5	1,378.9	1,354.3	1,323.4	1,267.5	1,248.7	1,223.6	1,204.7	1,166.6	1,134.7	1,121.8	1,102.5	1,063.6	1,037.4	1,030.8	971.2	951.0	917.2
	Total Production Cost (cents/1,000 gal)	12.1	9.9	9.7	9.3	9.1	8.9	8.4	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.4	7.3	7.3	7.2	7.1	7.0	7.0	6.8	6.8	6.7	6.5	6.5	6.4
>1,000,000	Total Capital Cost (K$)	80,946	74,609	73,753	72,759	68,399	67,851	66,135	65,334	61,416	61,098	60,865	60,674	60,431	59,979	59,823	59,612	59,450	59,118	58,832	58,715	58,536	58,160	57,913	54,484	54,071	53,926	53,674
517.491	O&M Cost (K$/year)	9,594.3	8,561.2	8,182.2	7,698.7	7,204.9	6,934.5	6,134.5	5,780.8	5,465.9	5,308.4	5,195.3	5,104.4	4,990.4	4,783.7	4,714.4	4,621.6	4,501.8	4,411.5	4,293.4	4,246.0	4,174.8	4,031.2	3,934.8	3,780.5	3,547.7	3,479.4	3,364.6
	Total Production Cost (cents/1,000 gal)	11.0	9.8	9.5	9.2	8.7	8.5	7.9	7.7	7.2	7.1	7.1	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.4	6.4	6.3	6.2	5.8	5.7	5.7	5.6

MGD= million gallons per day

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Table 7-42 ESTIMATED COST FOR REMOVING TETRACHLOROETHYLENE BY GRANULAR ACTIVATED CARBON ADSORPTION

System Size Population Range Average Daily Flow (MGD)		Influent																															
		500 (ug/L)							200 (ug/L)							100 (ug/L)						50 (ug/L)					20 (ug/l)				10 (ug/L)		5 (ug/L)
		Effluent (ug/L)							Effluent (ug/L)							Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)		Effluent (ug/L)
		1	5	10	15	20	50	100	1	5	10	15	20	50	100	1	5	10	15	20	50	1	5	10	15	20	1	5	10	15	1	5	1
25-100 0.013	Total Capital Cost (K$)	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	O&M Cost (K$/year)	1.1	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	Total Production Cost (cents/1,000 gal)	59.9	57.6	57.6	55.6	55.6	55.6	55.6	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	53.5	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4
101-500 0.057	Total Capital Cost (K$)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	O&M Cost (K$/year)	3.2	2.8	2.7	2.7	2.6	2.6	2.5	2.4	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.0
	Total Production Cost (cents/1,000 gal)	47.8	44.8	43.8	43.8	43.0	43.0	42.3	41.6	41.6	40.8	40.8	40.8	40.8	40.8	40.8	40.1	40.1	40.1	40.1	40.1	40.1	40.1	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	39.3	38.6
501-1,000 0.098	Total Capital Cost (K$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
	O&M Cost (K$/year)	7.1	6.2	5.9	5.8	5.7	5.5	5.4	5.2	5.0	4.9	4.9	4.8	4.8	4.7	4.7	4.6	4.6	4.6	4.5	4.5	4.5	4.4	4.4	4.4	4.4	4.3	4.3	4.3	4.3	4.2	4.2	4.2
	Total Production Cost (cents/1,000 gal)	39.0	37.2	36.3	35.8	35.7	35.1	34.8	34.3	33.7	33.4	33.4	33.1	33.1	[illegible]	32.8	32.5	32.5	32.5	32.2	32.2	32.2	31.9	31.9	31.9	31.9	31.6	31.6	31.6	31.6	31.3	31.3	31.3
1,001-3,300 0.280	Total Capital Cost (K$)	78	78	78	78	78	78	78	78	78	78	78	78	78	[illegible]	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78	78
	O&M Cost (K$/year)	16.5	13.9	13.2	12.8	12.4	11.9	11.5	10.9	10.3	10.1	10.0	9.9	9.7	9.6	9.6	9.3	9.2	9.1	9.0	9.0	8.9	8.7	8.6	8.6	8.6	8.4	8.3	8.3	8.3	8.1	8.0	7.9
	Total Production Cost (cents/1,000 gal)	26.0	23.6	23.1	22.7	22.4	21.9	21.5	20.9	20.3	20.1	20.0	19.9	19.7	19.6	19.6	19.3	19.2	19.1	19.0	19.0	18.9	18.7	18.6	18.6	18.6	18.4	18.3	18.3	18.3	18.1	18.0	17.9
3,301-10,000 0.952	Total Capital Cost (K$)	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
	O&M Cost (K$/year)	55.9	44.7	42.1	40.8	39.5	37.7	36.4	34.9	32.2	31.7	31.2	30.9	30.4	29.9	29.1	28.9	28.6	28.3	28.1	27.8	27.5	27.0	26.8	26.5	26.1	26.0	25.7	25.8	25.5	24.9	24.7	24.2
	Total Production Cost (cents/1,000 gal)	24.6	22.0	21.2	20.8	20.5	19.9	19.6	19.0	18.4	18.2	18.1	18.0	17.8	17.7	17.7	17.4	17.3	17.2	17.2	17.1	17.0	16.9	16.8	16.7	16.7	16.6	16.5	16.4	16.4	16.3	16.2	16.1
10,001-25,000 2.700	Total Capital Cost (K$)	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815
	O&M Cost (K$/year)	81.9	88.4	80.9	77.1	75.4	68.1	64.3	58.3	52.5	50.8	49.5	48.5	47.0	46.5	45.5	42.5	41.7	41.0	40.2	39.5	38.7	37.2	36.4	35.7	35.7	34.2	33.4	32.7	32.7	31.2	30.4	28.9
	Total Production Cost (cents/1,000 gal)	19.0	19.7	18.9	18.5	18.2	17.6	17.3	16.7	16.1	15.9	15.8	15.7	15.5	15.4	15.4	15.1	15.0	14.9	14.9	14.8	14.7	14.6	14.5	14.4	14.4	14.3	14.2	14.1	14.1	14.0	13.9	13.7
25,001-50,000 6.000	Total Capital Cost (K$)	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553
	O&M Cost (K$/year)	179.5	140.8	129.7	124.2	118.6	110.9	100.3	96.5	87.6	85.4	107.6	105.9	102.6	99.3	99.3	92.6	90.9	89.5	87.6	86.0	84.3	81.0	79.3	77.7	77.7	74.3	72.7	71.0	71.0	67.7	66.0	62.7
	Total Production Cost (cents/1,000 gal)	17.5	15.8	15.3	15.0	14.7	14.4	14.1	13.8	13.3	13.2	14.3	14.2	14.0	13.9	13.9	13.6	13.5	13.4	13.3	13.3	13.2	13.1	13.0	12.9	12.9	12.7	12.7	12.6	12.6	12.5	12.4	12.2
50,001-75,000 11.600	Total Capital Cost (K$)	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234
	O&M Cost (K$/year)	306.4	261.0	240.5	229.9	219.2	204.3	193.6	176.6	159.8	155.3	151.0	148.9	144.6	140.3	140.3	131.8	129.7	127.5	125.4	123.3	121.1	116.9	114.8	112.6	112.6	108.4	130.7	127.5	127.5	121.1	118.0	111.6
	Total Production Cost (cents/1,000 gal)	14.9	13.2	12.7	12.4	12.2	11.8	11.6	11.2	10.8	10.7	10.6	10.5	10.4	10.3	10.3	10.1	10.1	10.0	10.0	9.9	9.9	9.8	9.7	9.7	9.7	9.6	10.1	10.0	10.0	9.9	9.8	9.6
75,000-100,000 15.912	Total Capital Cost (K$)	4,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930	2,930
	O&M Cost (K$/year)	240.2	300.9	301.0	307.3	292.6	272.5	259.0	234.7	211.5	205.7	199.5	197.0	191.2	188.4	185.4	173.7	170.0	167.5	165.0	162.1	159.2	153.4	150.5	147.6	147.6	141.8	138.9	136.0	136.0	130.2	127.3	145.2
	Total Production Cost (cents/1,000 gal)	14.6	11.9	11.4	11.1	10.9	10.5	10.3	9.9	9.5	9.4	9.3	9.2	9.1	9.0	9.0	8.8	8.8	8.7	8.7	8.6	8.6	8.5	8.4	8.4	8.4	8.3	8.2	8.2	8.2	8.1	8.0	8.4
100,001-500,000 36.000	Total Capital Cost (K$)	8,044	7,675	7,554	7,491	7,426	7,331	7,260	7,139	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137	5,137
	O&M Cost (K$/year)	460.8	396.6	378.4	364.7	353.9	351.0	349.1	328.4	494.4	471.0	457.6	448.8	437.4	424.0	424.0	397.1	390.4	383.7	376.9	370.2	363.5	350.1	343.4	336.6	336.6	323.2	316.5	309.8	309.8	296.3	289.6	276.2
	Total Production Cost (cents/1,000 gal)	11.5	10.5	10.3	10.2	10.0	10.0	9.8	9.6	8.7	8.6	8.5	8.5	8.4	8.3	8.3	8.1	8.0	8.0	7.9	7.9	7.8	7.7	7.7	7.6	7.6	7.5	7.5	7.4	7.4	7.3	7.3	7.2
500,001-1,000,000 129.421	Total Capital Cost (K$)	17,289	16,637	16,429	16,330	16,287	16,042	15,910	15,709	15,481	15,421	15,399	15,320	15,264	15,179	15,190	15,060	15,085	15,060	14,951	14,914	14,875	14,795	14,756	14,714	14,714	14,629	14,594	14,590	14,539	14,444	14,380	14,290
	O&M Cost (K$/year)	1,415.6	1,198.3	1,134.7	1,102.8	1,070.1	1,004.2	991.2	957.6	885.0	869.2	850.3	840.3	834.3	820.2	820.2	791.7	784.5	787.0	770.1	762.6	755.8	740.6	735.4	726.0	726.0	711.0	708.0	693.9	682.9	704.1	695.2	677.2
	Total Production Cost (cents/1,000 gal)	7.9	7.3	7.1	7.0	6.9	6.7	6.6	6.4	6.3	6.2	6.2	6.1	6.1	6.0	6.0	5.9	5.9	5.9	5.9	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.6	5.6	5.6	5.6	5.6	5.5
>1,000,000 517.401	Total Capital Cost (K$)	61,144	59,395	58,602	58,355	58,220	54,440	54,213	53,657	53,409	53,290	53,160	53,120	53,010	52,880	52,809	52,626	52,570	52,625	52,436	52,316	52,276	52,181	52,075	52,000	52,000	51,845	51,751	51,670	51,670	51,594	51,414	51,230
	O&M Cost (K$/year)	5,301.6	4,588.4	4,295.4	4,174.8	4,088.3	3,729.2	3,610.7	3,435.6	3,249.6	3,201.8	3,184.8	3,136.2	3,088.8	3,036.1	3,036.1	2,929.9	2,918.7	2,921.0	2,867.0	2,842.8	2,817.5	2,780.4	2,743.8	2,718.8	2,718.8	2,680.1	2,642.8	2,617.3	2,617.3	2,560.8	2,555.9	2,487.8
	Total Production Cost (cents/1,000 gal)	7.2	6.6	6.4	6.4	6.3	5.8	5.8	5.6	5.5	5.5	5.4	5.4	5.4	5.4	5.4	5.3	5.3	5.3	5.2	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.1	5.0	5.0	5.0	5.0	4.9

MGD= million gallons per day

Table 7-43 ESTIMATED COST FOR REMOVING CARBON TETRACHLORIDE BY GRANULAR ACTIVATED CARBON ADSORPTION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
0.013	O&M Cost (K$/year)	2.3	2.0	1.9	1.8	1.7	1.6	2.0	1.8	1.7	1.6	1.6	1.5	1.8	1.7	1.6	1.5	1.5	1.7	1.6	1.5	1.4	1.6	1.5	1.4	1.5	1.4	1.4
	Total Production Cost (cents/1,000 gal)	80.2	78.8	76.7	74.6	72.5	70.4	78.8	74.6	72.5	70.4	70.4	68.3	74.6	72.5	70.4	68.3	68.3	72.5	70.4	68.3	66.2	70.4	68.3	66.2	68.3	66.2	66.2
101-500	Total Capital Cost (K$)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
0.037	O&M Cost (K$/year)	6.6	5.7	5.4	5.0	4.8	4.6	5.7	5.1	4.8	4.6	4.4	4.3	5.2	4.7	4.5	4.3	4.2	4.8	4.4	4.3	4.1	4.5	4.2	4.1	4.2	4.0	4.0
	Total Production Cost (cents/1,000 gal)	72.7	66.0	63.0	60.8	59.3	57.9	66.0	61.6	59.3	57.9	56.4	55.6	62.3	58.6	57.1	55.6	54.9	59.3	56.4	55.6	54.2	57.1	54.9	54.2	54.9	53.4	53.4
501-1,000	Total Capital Cost (K$)	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48
0.043	O&M Cost (K$/year)	15.7	13.3	12.8	11.7	11.1	10.7	13.4	11.7	11.2	10.6	10.2	9.8	12.2	10.9	10.4	9.9	9.6	11.2	10.2	9.8	9.4	10.4	9.6	9.3	9.6	9.0	9.2
	Total Production Cost (cents/1,000 gal)	68.2	58.1	55.8	53.4	51.6	50.5	58.4	53.4	51.9	50.2	49.0	47.8	54.9	51.0	49.6	48.1	47.2	51.9	49.0	47.8	46.6	49.6	47.2	46.3	47.2	45.4	46.0
1,001-3,300	Total Capital Cost (K$)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
0.280	O&M Cost (K$/year)	42.6	35.3	33.0	30.5	28.9	27.4	35.6	30.7	29.0	27.2	26.0	24.9	32.0	28.1	26.7	25.3	24.3	29.0	26.0	24.9	23.7	26.7	24.3	23.4	24.4	22.4	22.9
	Total Production Cost (cents/1,000 gal)	51.9	44.8	42.5	40.1	38.5	37.0	45.1	40.3	38.6	36.8	35.7	34.6	41.5	37.7	36.3	35.0	34.0	38.6	35.7	34.6	33.4	36.3	34.0	33.1	34.1	32.1	32.6
3,301-10,000	Total Capital Cost (K$)	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
0.952	O&M Cost (K$/year)	101.4	84.9	79.7	73.9	70.3	90.6	85.6	74.5	70.6	69.8	65.7	82.0	77.2	93.0	88.3	83.3	79.9	70.6	65.7	82.0	77.0	88.3	79.9	76.0	80.2	73.4	75.2
	Total Production Cost (cents/1,000 gal)	38.5	33.5	32.0	30.4	29.3	35.2	33.7	30.5	29.4	34.9	33.8	32.7	31.3	35.9	34.5	33.1	32.1	29.4	33.8	32.7	31.5	34.9	32.1	31.2	32.2	30.2	30.7
10,001-25,000	Total Capital Cost (K$)	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815
2.753	O&M Cost (K$/year)	252.2	204.5	189.4	172.9	162.3	152.0	206.5	174.4	163.3	151.3	143.2	136.2	182.4	157.3	148.2	138.7	132.2	163.3	145.2	136.2	128.1	148.2	132.2	126.1	132.7	119.6	123.1
	Total Production Cost (cents/1,000 gal)	36.0	31.2	29.7	28.1	27.0	26.1	31.4	28.2	27.1	25.9	25.1	24.4	29.0	26.5	25.6	24.7	24.0	27.1	25.1	24.4	23.6	25.6	24.0	23.4	24.1	22.8	23.1
25,001-50,000	Total Capital Cost (K$)	3,861	3,643	3,568	1,553	1,553	1,553	3,653	1,553	1,553	1,553	1,553	1,555	3,532	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553
6.065	O&M Cost (K$/year)	229.6	215.9	203.2	379.0	356.6	335.6	217.6	383.2	358.0	337.2	314.5	299.0	197.2	345.5	325.6	304.6	290.2	358.0	314.5	299.0	281.3	325.6	290.2	276.9	291.3	262.5	270.3
	Total Production Cost (cents/1,000 gal)	33.7	31.8	30.8	26.5	25.5	24.6	31.9	26.7	25.6	24.4	23.6	22.9	30.3	25.0	24.1	23.2	22.5	25.6	23.6	22.9	22.1	24.1	22.5	21.9	22.6	21.2	21.6
50,001-75,000	Total Capital Cost (K$)	5,311	5,021	4,921	4,805	4,727	4,654	5,034	4,816	4,735	4,643	4,579	4,521	4,872	4,689	4,619	4,542	4,487	4,735	4,579	4,521	4,452	4,619	4,487	4,438	4,491	4,376	4,408
11.680	O&M Cost (K$/year)	400.4	339.6	320.0	298.2	284.1	271.3	342.2	300.2	285.5	269.3	258.4	248.8	310.8	277.4	265.2	252.2	267.9	285.5	258.4	248.8	261.5	265.2	267.9	258.3	260.7	247.8	283.4
	Total Production Cost (cents/1,000 gal)	26.1	23.7	23.0	22.1	21.5	21.0	23.8	22.2	21.6	20.9	20.4	20.0	22.6	21.2	20.7	20.2	20.4	21.6	20.4	20.0	20.1	20.7	20.4	20.0	20.4	19.6	19.8
75,000-100,000	Total Capital Cost (K$)	6,063	5,730	5,615	5,482	5,394	5,310	5,745	5,498	5,402	5,297	5,224	5,157	5,560	5,350	5,270	5,181	5,118	5,402	5,224	5,157	5,079	5,270	5,118	5,089	5,123	4,992	5,028
15.912	O&M Cost (K$/year)	520.7	441.0	415.3	386.8	368.4	351.6	444.4	389.4	370.1	348.9	334.7	322.1	403.2	359.6	343.6	326.6	314.9	370.1	334.7	322.1	307.6	343.6	314.9	304.0	318.8	292.1	298.8
	Total Production Cost (cents/1,000 gal)	22.9	20.8	20.1	19.3	18.8	18.3	20.9	19.4	18.8	18.2	17.8	17.4	19.8	18.5	18.1	17.6	17.2	18.8	17.8	17.4	17.0	18.1	17.2	16.9	17.2	16.5	16.7
100,001-500,000	Total Capital Cost (K$)	10,230	9,750	9,584	9,392	9,264	9,143	9,771	9,410	9,276	9,124	9,018	8,922	9,504	9,201	9,094	8,957	8,866	9,276	9,018	8,922	8,809	9,094	8,866	8,780	8,873	8,683	8,730
36.806	O&M Cost (K$/year)	1,092.8	926.3	872.7	813.1	774.8	739.9	933.4	818.6	778.5	734.3	704.6	678.4	847.5	756.5	723.2	687.8	663.4	778.5	704.6	678.4	648.3	723.2	663.4	640.7	668.3	616.0	629.3
	Total Production Cost (cents/1,000 gal)	18.3	16.6	16.0	15.4	15.0	14.6	16.7	15.5	15.0	14.6	14.2	13.9	15.8	14.8	14.4	14.0	13.8	15.0	14.2	13.9	13.6	14.4	13.8	13.5	13.8	13.2	13.4
500,001-1,000,000	Total Capital Cost (K$)	25,300	24,067	23,641	23,149	22,820	19,190	24,122	23,190	22,852	19,136	18,972	18,806	23,436	22,659	19,088	18,866	18,708	22,852	18,972	18,806	18,609	19,088	18,708	18,580	18,720	18,390	18,481
129.421	O&M Cost (K$/year)	3,580.7	3,006.6	2,830.1	2,633.9	2,507.7	2,236.3	3,030.0	2,601.8	2,519.0	2,219.4	2,129.2	2,049.8	2,747.1	2,447.3	2,185.7	2,078.2	2,004.1	2,519.0	2,129.2	2,049.8	1,958.3	2,185.7	2,004.1	1,935.4	2,089.9	1,860.4	1,980.8
	Total Production Cost (cents/1,000 gal)	14.7	13.2	12.7	12.1	11.8	10.2	13.3	12.2	11.8	10.1	9.9	9.7	12.5	11.6	10.0	9.7	9.5	11.8	9.9	9.7	9.4	10.0	9.5	9.4	9.6	9.2	9.3
>1,000,000	Total Capital Cost (K$)	96,032	87,808	82,338	81,041	80,029	75,342	87,993	81,183	80,127	75,286	74,469	73,802	81,925	79,532	74,933	74,042	73,411	80,127	74,469	73,802	73,012	74,933	73,411	72,809	75,460	68,444	72,902
317.491	O&M Cost (K$/year)	14,008.9	11,687.3	10,774.6	10,029.7	9,551.2	8,922.0	11,748.1	10,097.8	9,596.9	8,604.6	8,493.3	8,175.0	10,489.6	9,322.0	8,719.4	8,288.9	7,952.2	9,596.9	8,493.3	8,175.0	7,858.8	8,719.4	7,952.2	7,716.7	8,018.1	7,227.3	7,878.3
	Total Production Cost (cents/1,000 gal)	14.2	12.4	11.6	11.1	10.7	10.1	12.5	11.1	10.8	10.0	9.8	9.6	11.3	10.6	9.9	9.6	9.4	10.8	9.8	9.6	9.3	9.9	9.4	9.2	9.5	8.7	9.2

MGD= million gallons per day

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Table 7-44 ESTIMATED COST FOR REMOVING 1,2-DICHLOROETHANE BY GRANULAR ACTIVATED CARBON ADSORPTION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
0.013	O&M Cost (K$/year)	4.1	3.3	3.0	2.8	2.6	2.5	3.4	2.8	2.7	2.5	2.4	2.3	3.0	2.6	2.5	2.3	2.2	2.7	2.4	2.3	2.2	2.5	2.2	2.2	2.3	2.1	2.1
	Total Production Cost (cents/1,000 gal)	123.1	106.2	99.9	95.7	91.8	89.4	108.3	98.7	93.6	89.4	87.3	85.2	99.9	91.5	89.4	85.2	83.0	93.6	87.3	85.2	83.0	89.4	83.0	83.0	85.2	80.9	80.9
101-500	Total Capital Cost (K$)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
0.037	O&M Cost (K$/year)	11.6	9.4	8.7	8.0	7.5	7.1	9.6	8.1	7.6	7.1	6.8	6.5	8.5	7.4	7.0	6.6	6.3	7.7	6.9	6.5	6.2	7.1	6.4	6.1	6.5	5.9	6.1
	Total Production Cost (cents/1,000 gal)	109.7	93.4	88.7	83.0	79.5	76.4	94.9	83.8	80.1	76.4	74.1	71.9	86.7	78.6	75.6	72.7	70.4	80.8	74.9	71.9	69.7	76.4	71.2	69.0	71.9	67.8	69.0
501-1,000	Total Capital Cost (K$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
0.093	O&M Cost (K$/year)	28.2	22.6	20.9	19.1	17.9	16.9	23.1	19.4	18.2	16.9	16.1	15.3	20.8	17.7	16.7	15.6	14.9	18.5	16.3	15.5	14.6	16.9	15.1	14.6	15.3	13.9	14.3
	Total Production Cost (cents/1,000 gal)	102.0	88.5	80.5	75.2	71.7	68.7	87.0	76.1	72.5	68.7	66.4	64.0	79.3	71.1	68.1	64.9	62.8	73.4	67.0	64.6	61.9	68.7	63.4	61.6	64.0	58.9	61.1
1,001-3,300	Total Capital Cost (K$)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
0.280	O&M Cost (K$/year)	80.2	63.3	58.2	52.7	49.3	46.4	65.0	53.8	50.5	46.5	43.7	41.5	57.1	48.5	45.7	42.5	40.3	51.0	44.3	42.0	38.3	46.3	40.8	38.9	41.4	37.1	38.3
	Total Production Cost (cents/1,000 gal)	88.7	72.2	67.2	61.8	58.3	55.6	73.0	62.9	59.4	55.5	53.0	50.8	66.1	57.7	54.9	51.8	49.7	60.1	53.6	51.3	48.7	55.8	50.1	48.3	50.7	46.5	47.9
3,301-10,000	Total Capital Cost (K$)	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
0.952	O&M Cost (K$/year)	186.7	148.3	136.0	124.3	116.5	109.9	152.1	126.0	118.0	109.7	103.8	98.8	134.2	114.8	108.3	101.0	96.2	120.5	105.2	100.0	98.9	100.7	97.4	93.0	98.6	88.9	92.0
	Total Production Cost (cents/1,000 gal)	62.0	51.0	48.5	44.9	42.6	40.7	52.9	43.6	43.5	40.7	39.0	37.5	47.7	42.1	40.3	36.2	36.8	43.0	39.4	37.9	36.1	40.7	37.1	35.9	37.8	34.7	35.6
10,001-25,000	Total Capital Cost (K$)	3,049	2,085	815	815	815	815	2,032	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815
2.753	O&M Cost (K$/year)	223.2	180.9	354.7	318.6	298.9	276.9	185.1	325.6	302.5	276.4	259.3	244.7	347.2	298.9	272.3	251.2	237.2	307.8	263.3	[illegible]	238.6	276.4	240.7	228.1	244.2	216.1	228.1
	Total Production Cost (cents/1,000 gal)	62.0	55.4	46.2	42.6	40.3	38.4	56.2	43.3	41.0	39.4	36.7	35.2	45.4	39.8	38.0	35.9	34.5	41.8	37.1	35.6	35.0	38.4	34.0	33.6	35.2	32.4	33.3
25,001-50,000	Total Capital Cost (K$)	4,712	4,370	4,287	4,126	4,040	3,964	4,406	4,152	4,068	3,962	3,891	3,820	4,230	4,020	3,940	3,807	3,750	4,084	3,908	3,844	3,766	3,962	3,811	3,754	3,826	3,690	3,741
6.068	O&M Cost (K$/year)	395.0	322.9	300.6	275.9	260.2	246.9	330.3	280.7	264.8	246.6	234.8	224.2	295.4	256.0	243.7	228.0	243.1	260.5	237.4	[illegible]	257.7	246.6	246.1	238.7	225.0	225.6	233.1
	Total Production Cost (cents/1,000 gal)	46.4	41.0	39.3	37.4	36.2	35.1	41.6	37.0	36.5	35.1	34.1	33.3	38.9	35.9	34.9	33.7	33.9	36.0	34.4	33.5	33.8	35.1	34.2	33.4	33.2	32.6	33.2
50,001-75,000	Total Capital Cost (K$)	6,446	5,990	5,859	5,660	5,549	5,448	6,038	5,699	5,583	5,446	5,351	5,260	5,804	5,523	5,424	5,306	5,223	5,609	5,374	5,288	5,184	5,446	5,244	5,169	5,260	5,088	5,151
11.680	O&M Cost (K$/year)	698.8	560.0	526.2	482.4	454.8	431.2	578.9	491.0	462.8	430.5	409.2	390.9	517.1	448.6	420.5	399.2	381.4	468.9	414.3	398.4	373.1	430.8	385.9	369.9	390.3	354.5	366.1
	Total Production Cost (cents/1,000 gal)	36.6	32.1	30.7	29.1	28.1	27.2	32.5	29.4	28.4	27.2	26.4	25.7	30.4	27.9	27.0	26.0	25.5	28.6	26.6	25.9	25.8	27.2	25.8	24.9	25.7	24.3	24.8
75,001-100,000	Total Capital Cost (K$)	7,363	6,840	6,667	6,467	6,335	6,220	6,896	6,507	6,374	6,216	6,108	6,015	6,626	6,305	6,191	6,056	5,962	6,404	6,134	6,036	5,917	6,216	5,986	5,900	6,009	5,815	5,879
15.912	O&M Cost (K$/year)	907.8	737.6	688.6	628.2	591.9	561.0	754.8	639.4	602.4	560.2	532.3	508.3	673.7	583.8	553.6	519.0	495.8	610.5	538.8	514.1	484.9	560.2	501.6	480.7	507.4	460.5	478.7
	Total Production Cost (cents/1,000 gal)	32.6	28.5	27.2	25.7	24.8	24.0	28.9	26.0	25.1	24.0	23.2	22.6	26.9	24.6	23.8	22.9	22.3	25.3	23.4	22.8	22.0	24.0	22.4	21.9	22.6	21.3	21.7
100,001-500,000	Total Capital Cost (K$)	12,109	11,353	11,104	10,818	10,625	10,457	11,434	10,873	10,680	10,452	10,296	10,158	11,045	10,581	10,416	10,221	10,080	10,723	10,334	10,192	10,000	10,452	10,119	9,998	10,153	9,872	9,980
35.806	O&M Cost (K$/year)	1,904.6	1,547.1	1,438.1	1,317.0	1,241.0	1,177.1	1,583.2	1,341.3	1,263.0	1,178.4	1,117.0	1,066.0	1,413.2	1,224.0	1,161.7	1,089.3	1,040.7	1,280.0	1,150.8	1,078.9	1,018.0	1,178.4	1,052.9	1,029.2	1,065.0	967.0	998.7
	Total Production Cost (cents/1,000 gal)	26.2	22.8	21.8	20.6	19.8	19.2	23.2	20.0	20.1	19.2	18.6	18.1	21.5	19.7	18.8	18.3	17.8	20.2	18.7	18.2	17.6	19.2	17.9	17.8	18.0	17.0	17.4
500,001-1,000,000	Total Capital Cost (K$)	38,609	32,272	31,467	30,536	26,312	25,862	32,531	30,722	30,162	25,870	25,470	25,115	31,277	26,200	25,777	25,276	24,927	30,279	25,568	25,202	24,761	25,870	25,018	24,696	25,103	24,380	24,618
129.421	O&M Cost (K$/year)	6,730.6	5,284.7	4,907.9	4,491.9	4,047.5	3,833.6	5,409.5	4,573.2	4,308.3	3,868.2	3,635.5	3,469.9	4,821.6	3,991.5	3,703.6	3,544.2	3,383.0	4,363.7	3,680.9	3,509.9	3,388.9	3,880.2	3,424.0	3,280.0	3,464.1	3,140.9	3,248.3
	Total Production Cost (cents/1,000 gal)	25.2	20.3	19.3	18.2	16.0	15.3	20.7	18.4	17.6	15.4	14.9	14.5	19.1	15.9	15.3	14.7	14.2	17.8	15.8	14.6	14.8	18.4	14.3	13.9	14.4	13.6	13.8
>1,000,000	Total Capital Cost (K$)	145,749	125,960	117,832	109,869	103,980	102,180	124,956	110,582	108,390	102,134	96,665	93,365	116,368	103,457	101,761	95,961	94,665	108,057	100,911	95,687	94,047	102,130	94,993	93,007	95,319	88,873	97,685
517.451	O&M Cost (K$/year)	26,340.6	20,980.6	19,288.6	18,486.7	16,177.3	15,521.4	21,425.5	17,716.8	16,670.2	15,298.8	14,523.7	13,670.4	18,890.3	15,982.7	15,117.7	15,963.8	13,530.7	16,984.7	14,709.0	13,880.5	13,888.2	15,280.0	13,489.4	12,921.3	13,647.8	12,177.7	12,882.6
	Total Production Cost (cents/1,000 gal)	24.4	19.9	18.5	17.6	15.9	15.4	20.2	17.2	16.5	15.3	14.4	14.0	18.3	15.8	15.2	14.2	13.8	16.7	14.9	14.1	13.6	15.3	13.9	13.5	14.8	12.7	13.0

MGD= million gallons per day

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Table 7-45 ESTIMATED COST FOR REMOVING 1,1-DICHLOROETHYLENE BY GRANULAR ACTIVATED CARBON ADSORPTION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/L)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100	Total Capital Cost (K$)	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
0.013	O&M Cost (K$/year)	1.9	1.6	1.8	1.4	1.4	1.3	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
	Total Production Cost (cents/1,000 gal)	76.7	70.4	68.3	66.2	66.2	64.1	62.0	59.9	59.9	59.9	57.8	57.8	57.8	57.8	57.8	55.6	55.6	55.6	55.6	55.6	55.6	55.6	55.6	53.5	53.5	53.5	53.5
101-500	Total Capital Cost (K$)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
0.037	O&M Cost (K$/year)	5.3	4.6	4.4	4.1	3.9	3.7	3.3	3.1	3.1	3.0	3.0	2.9	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.3
	Total Production Cost (cents/1,000 gal)	64.5	57.9	56.4	54.2	52.7	51.2	48.2	46.7	46.7	46.0	46.0	45.3	45.3	44.5	44.5	43.0	43.0	43.0	43.0	43.0	42.3	42.3	41.6	41.6	41.6	40.8	40.8
501-1,000	Total Capital Cost (K$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
0.093	O&M Cost (K$/year)	12.9	10.6	10.0	9.3	8.8	8.4	7.3	6.9	6.8	6.6	6.5	6.4	6.2	6.0	5.9	5.8	5.8	5.6	5.5	5.5	5.4	5.3	5.2	5.2	5.0	4.9	4.8
	Total Production Cost (cents/1,000 gal)	56.9	50.2	48.4	46.3	44.9	43.7	40.4	39.5	39.0	38.4	38.1	37.8	37.2	36.6	36.5	36.0	36.0	35.4	35.1	35.1	34.8	34.5	34.3	34.3	33.7	33.4	33.1
1,001-3,300	Total Capital Cost (K$)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
0.280	O&M Cost (K$/year)	34.5	27.4	25.4	23.2	21.9	20.8	17.5	16.2	15.8	15.2	14.9	14.6	14.1	13.5	13.2	12.9	12.7	12.5	11.9	11.8	11.6	11.2	10.9	10.9	10.5	10.1	9.7
	Total Production Cost (cents/1,000 gal)	43.8	37.0	35.1	32.9	31.6	30.6	27.3	26.1	25.7	25.1	24.8	24.5	24.0	23.4	23.1	22.8	22.6	22.3	21.9	21.8	21.6	21.2	20.9	20.9	20.5	20.1	19.7
3,301-10,000	Total Capital Cost (K$)	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
0.952	O&M Cost (K$/year)	97.5	90.4	83.6	76.3	71.9	67.9	56.7	52.6	51.0	49.2	47.9	46.8	45.3	43.2	42.4	41.4	40.6	39.0	38.0	37.5	36.7	35.4	34.6	34.3	32.2	31.7	30.4
	Total Production Cost (cents/1,000 gal)	37.8	35.1	33.2	31.1	29.8	28.6	25.4	24.2	23.8	23.3	22.9	22.6	22.1	21.5	21.3	21.0	20.8	20.5	20.0	19.9	19.7	19.3	19.1	19.0	18.4	18.2	17.8
10,001-25,000	Total Capital Cost (K$)	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815
2.753	O&M Cost (K$/year)	197.5	152.3	139.2	125.1	116.6	109.0	87.4	79.4	76.4	72.9	70.4	68.4	90.0	83.9	81.7	78.7	76.4	71.9	68.9	67.3	65.1	64.3	59.1	58.3	52.3	50.8	47.0
	Total Production Cost (cents/1,000 gal)	30.5	26.0	24.7	23.3	22.5	21.7	19.6	18.8	18.5	18.1	17.9	17.7	19.8	19.2	19.0	18.7	18.5	18.0	17.7	17.6	17.3	17.0	16.7	16.7	16.1	15.9	15.5
25,001-50,000	Total Capital Cost (K$)	3,609	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353	1,353
6.065	O&M Cost (K$/year)	218.0	334.5	300.7	274.7	258.9	239.3	191.7	174.0	167.3	159.6	154.0	149.6	143.0	134.1	130.0	126.4	121.0	116.4	112.0	109.0	106.4	100.9	97.6	96.5	87.6	85.4	102.6
	Total Production Cost (cents/1,000 gal)	31.3	24.5	23.2	21.8	21.0	20.2	18.1	17.3	16.9	16.6	16.3	16.1	15.9	15.4	15.3	15.1	14.9	14.7	14.5	14.4	14.2	14.0	13.8	13.8	13.3	13.2	14.0
50,001-75,000	Total Capital Cost (K$)	4,975	4,601	4,546	4,426	4,349	4,270	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234
11.680	O&M Cost (K$/year)	330.5	270.6	262.9	256.6	242.9	230.7	309.9	325.0	313.0	298.1	287.4	278.9	266.1	249.0	242.6	234.1	227.7	214.9	206.4	202.1	190.0	185.1	178.7	176.6	160.5	155.3	144.6
	Total Production Cost (cents/1,000 gal)	23.4	21.0	20.2	19.9	19.4	18.8	15.3	14.7	14.4	14.0	13.8	13.6	13.3	12.9	12.7	12.5	12.4	12.1	11.9	11.8	11.6	11.4	11.2	11.2	10.8	10.7	10.4
75,000-100,000	Total Capital Cost (K$)	5,677	5,356	5,186	5,049	4,960	4,879	4,622	4,516	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530	2,530
15.912	O&M Cost (K$/year)	429.0	380.7	327.5	302.1	286.5	272.6	252.9	234.6	420.6	400.2	380.7	374.1	356.7	333.5	324.7	313.1	304.4	287.0	275.4	269.6	260.9	246.3	237.6	234.7	211.8	208.7	191.2
	Total Production Cost (cents/1,000 gal)	20.8	18.3	17.6	16.8	16.4	15.9	15.0	14.4	13.1	12.7	12.5	12.3	12.0	11.6	11.4	11.2	11.1	10.8	10.6	10.5	10.3	10.1	9.9	9.9	9.5	9.4	9.1
100,001-500,000	Total Capital Cost (K$)	9,673	9,137	8,963	8,760	8,637	8,519	8,149	7,995	7,934	7,861	7,808	7,764	7,696	7,602	7,566	7,516	7,478	7,399	7,345	7,317	7,274	7,200	7,154	7,139	5,137	5,137	5,137
36.006	O&M Cost (K$/year)	901.5	738.0	689.7	636.9	604.9	575.6	491.0	458.7	446.4	432.1	421.7	413.4	400.9	384.0	377.6	369.0	362.6	374.4	364.8	359.3	351.6	340.0	331.0	320.4	484.4	471.0	437.4
	Total Production Cost (cents/1,000 gal)	16.3	14.6	14.1	13.5	13.1	12.8	11.8	11.4	11.2	11.1	10.9	10.8	10.7	10.4	10.4	10.2	10.2	10.2	10.0	10.0	9.9	9.7	9.6	9.6	8.7	8.6	8.4
500,001-1,000,000	Total Capital Cost (K$)	23,871	19,170	18,877	18,558	18,311	18,186	17,462	17,195	17,090	16,965	16,870	16,794	16,677	16,513	16,450	16,364	16,258	16,161	16,086	16,010	15,943	15,815	15,736	15,700	15,481	15,421	15,264
[illegible]	O&M Cost (K$/year)	2,904.4	2,230.7	2,080.9	1,925.9	1,820.6	1,738.0	1,482.3	1,388.0	1,340.1	1,304.8	1,273.7	1,240.7	1,211.0	1,160.2	1,141.1	1,115.4	1,096.0	1,057.0	1,038.0	1,017.6	997.0	964.5	944.3	937.6	888.0	869.2	834.3
	Total Production Cost (cents/1,000 gal)	13.0	10.2	9.8	9.3	9.1	8.8	8.1	7.8	7.7	7.6	7.5	7.4	7.3	7.1	7.1	7.0	6.9	6.8	6.7	6.7	6.6	6.5	6.5	6.4	6.3	6.2	6.1
>1,000,000	Total Capital Cost (K$)	87,136	75,297	74,080	72,707	68,173	67,475	60,279	60,912	60,626	60,203	60,030	59,623	59,504	59,062	58,890	58,606	58,476	58,105	54,404	54,350	54,250	54,023	53,877	53,827	53,489	53,290	53,010
517.491	O&M Cost (K$/year)	11,338.9	8,899.6	8,511.7	7,670.7	7,092.4	6,753.2	5,762.4	5,217.9	5,081.7	4,921.7	4,886.8	4,714.4	4,578.1	4,397.8	4,317.0	4,222.3	4,180.9	4,007.2	3,780.5	3,780.7	3,638.2	3,520.0	3,488.3	3,430.6	3,240.6	3,201.0	3,050.0
	Total Production Cost (cents/1,000 gal)	12.2	10.0	9.7	9.2	8.6	8.4	7.7	7.1	7.0	6.9	6.8	6.7	6.6	6.5	6.5	6.4	6.3	6.2	5.8	5.8	5.8	5.7	5.6	5.6	5.5	5.5	5.4

Table 7-48 ESTIMATED COST FOR REMOVING BENZENE BY GRANULAR ACTIVATED CARBON ADSORPTION

System Size Population Range Average Daily Flow (MGD)		Influent																										
		500 (ug/L)						200 (ug/L)						100 (ug/L)					50 (ug/L)				25 (ug/l)			10 (ug/L)		5 (ug/L)
		Effluent (ug/L)						Effluent (ug/L)						Effluent (ug/L)					Effluent (ug/L)				Effluent (ug/L)			Effluent (ug/L)		Effluent (ug/L)
		1	5	10	25	50	100	1	5	10	25	50	100	1	5	10	25	50	1	5	10	25	1	5	10	1	5	1
25-100 0.013	Total Capital Cost (K$)	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	O&M Cost (K$/year)	12.2	5.5	4.0	2.6	2.0	1.5	5.2	2.6	1.9	1.4	1.1	0.9	2.9	1.6	1.3	1.0	0.8	1.8	1.1	0.9	0.8	1.2	0.8	0.8	0.9	0.7	0.7
	Total Production Cost (cents/1,000 gal)	295.0	152.6	121.0	91.5	78.0	68.3	146.5	91.5	76.7	66.2	59.9	55.6	97.0	70.4	64.1	57.8	53.5	74.6	59.9	55.6	53.5	62.0	53.5	53.5	55.6	51.4	51.4
101-500 0.037	Total Capital Cost (K$)	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24
	O&M Cost (K$/year)	34.7	15.7	11.4	7.8	5.6	4.2	15.0	7.3	5.6	4.0	3.1	2.4	6.4	4.5	3.6	2.8	2.3	5.1	3.1	2.6	2.2	3.3	2.4	2.2	2.3	2.0	2.1
	Total Production Cost (cents/1,000 gal)	280.7	140.0	108.2	79.3	60.3	50.9	134.9	77.0	60.3	53.4	46.7	41.6	65.0	57.1	50.4	44.5	40.0	61.6	46.7	43.0	40.1	45.7	41.6	40.1	40.3	38.6	39.5
501-1,000 0.093	Total Capital Cost (K$)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
	O&M Cost (K$/year)	58.7	38.6	27.6	18.0	13.1	9.5	36.5	17.5	13.0	9.0	6.0	5.2	20.1	10.4	8.1	6.0	4.8	11.0	6.9	5.7	4.5	7.7	5.1	4.8	5.2	4.1	4.4
	Total Production Cost (cents/1,000 gal)	191.9	132.6	100.2	72.0	57.5	46.9	126.0	70.5	57.2	45.4	35.0	34.3	70.1	49.6	42.8	36.6	33.1	53.7	39.3	35.7	32.2	41.6	34.0	32.2	34.3	31.0	31.9
1,001-3,300 0.288	Total Capital Cost (K$)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
	O&M Cost (K$/year)	172.1	76.6	70.6	49.5	34.7	23.9	72.6	48.0	34.5	22.4	15.9	10.9	58.9	26.7	19.0	15.3	9.7	51.0	16.2	12.5	8.8	10.5	10.0	8.8	11.0	7.7	8.6
	Total Production Cost (cents/1,000 gal)	178.6	88.2	87.1	58.7	44.2	35.6	81.3	57.2	44.0	32.1	25.8	20.9	64.9	36.5	29.6	25.2	19.7	60.6	26.1	22.4	18.8	20.5	20.0	18.8	21.0	17.8	18.6
3,301-10,000 0.952	Total Capital Cost (K$)	2,625	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236	236
	O&M Cost (K$/year)	228.5	207.8	182.9	117.0	83.5	78.6	244.2	113.5	88.0	73.4	51.5	34.6	131.4	80.3	64.6	42.7	30.4	78.0	62.3	39.0	27.3	60.4	34.1	27.3	34.0	23.4	26.5
	Total Production Cost (cents/1,000 gal)	166.9	85.5	61.7	42.0	33.1	31.7	79.4	41.0	33.0	30.2	25.9	19.1	46.9	34.5	27.7	21.4	17.8	30.7	24.1	20.5	16.9	26.5	18.9	16.9	19.1	18.0	16.7
10,001-25,000 2.753	Total Capital Cost (K$)	4,623	3,425	3,076	815	815	815	3,550	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815	815
	O&M Cost (K$/year)	580.0	264.3	219.0	297.5	280.5	179.6	252.1	287.4	190.0	119.6	77.4	59.1	335.2	148.2	102.5	82.4	47.0	175.9	70.9	74.1	38.0	94.5	57.3	38.0	59.0	26.7	28.7
	Total Production Cost (cents/1,000 gal)	115.2	71.9	62.1	40.8	30.8	23.8	69.0	39.5	30.7	22.0	18.6	16.7	44.6	25.6	21.1	19.1	15.5	28.4	18.7	18.2	14.6	20.5	15.6	14.6	16.0	13.8	14.4
25,001-50,000 6.045	Total Capital Cost (K$)	6,939	5,244	4,669	4,040	3,625	1,553	5,151	4,086	3,616	1,553	1,553	1,553	4,201	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553	1,553
	O&M Cost (K$/year)	1,075.0	525.0	380.6	261.3	212.5	244.7	501.6	254.3	211.2	262.5	160.5	97.6	290.0	525.6	224.9	131.9	102.6	395.5	172.9	119.7	82.6	287.2	98.4	82.6	98.7	87.7	77.7
	Total Production Cost (cents/1,000 gal)	90.5	50.5	40.9	35.3	31.5	22.3	53.8	35.7	31.4	21.2	17.0	13.8	38.5	24.1	19.6	15.4	14.0	20.9	17.2	14.8	13.1	18.8	13.7	13.1	13.9	12.8	12.9
50,001-75,000 11.469	Total Capital Cost (K$)	12,044	7,156	6,404	5,557	4,990	4,065	7,031	5,505	4,985	4,376	2,234	2,234	5,760	4,619	4,213	2,234	2,234	4,886	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234	2,234
	O&M Cost (K$/year)	2,072.4	926.7	682.8	486.6	384.4	265.9	883.4	444.2	352.4	247.8	317.3	178.7	507.4	460.2	220.0	244.8	144.6	390.2	323.7	221.3	119.0	380.7	174.4	119.0	180.0	100.0	112.6
	Total Production Cost (cents/1,000 gal)	88.9	44.2	36.1	28.2	23.5	20.2	42.0	27.7	23.5	19.6	14.5	11.2	30.0	20.7	18.4	12.8	10.4	23.2	14.6	12.2	9.0	16.2	11.1	9.0	11.3	9.4	9.7
75,001-100,000 15.912	Total Capital Cost (K$)	14,051	8,175	7,316	6,344	5,700	5,294	8,032	6,204	5,609	4,952	2,530	2,530	6,383	5,270	4,880	2,530	2,530	5,887	2,530	2,530	2,530	4,710	2,530	2,530	2,530	2,036	2,080
	O&M Cost (K$/year)	2,714.0	1,211.6	891.1	594.4	434.2	310.5	1,154.6	576.1	431.6	292.1	426.4	237.6	661.0	343.6	285.4	327.6	191.2	552.0	435.1	290.7	196.3	267.9	231.0	196.3	240.5	133.1	107.6
	Total Production Cost (cents/1,000 gal)	89.6	39.7	32.2	24.9	20.6	17.1	38.4	24.4	20.5	16.5	13.2	9.9	26.6	18.1	16.0	11.8	9.1	19.4	13.3	10.9	8.5	15.5	9.8	8.5	10.0	8.1	8.4
100,001-500,000 36.006	Total Capital Cost (K$)	31,081	17,172	12,039	10,630	9,706	8,930	16,066	10,500	9,650	8,605	7,584	7,154	10,982	9,084	8,413	7,579	5,137	9,420	7,580	7,490	5,137	8,276	7,123	5,137	7,170	5,137	5,137
	O&M Cost (K$/year)	6,170.5	2,753.0	1,259.4	1,246.9	912.0	604.0	2,621.2	1,212.9	986.7	646.0	480.5	351.0	1,336.8	723.2	580.3	379.7	487.4	824.0	685.6	586.1	386.0	518.0	329.0	386.0	333.6	286.0	380.6
	Total Production Cost (cents/1,000 gal)	76.9	37.6	25.9	19.9	16.5	13.7	36.3	19.5	16.4	13.2	11.3	9.6	21.5	14.4	12.5	10.4	8.4	15.5	11.4	10.1	7.8	12.1	9.5	7.8	9.6	7.0	7.6
500,001-1,000,000 129.421	Total Capital Cost (K$)	98,867	47,244	38,392	26,340	25,950	18,646	46,380	26,121	23,513	18,590	17,145	15,736	31,073	19,080	17,922	16,471	15,264	23,240	17,170	16,230	14,836	17,683	15,601	14,836	18,762	12,230	14,716
	O&M Cost (K$/year)	21,204.0	9,201.3	6,610.0	6,311.2	2,989.7	1,975.5	8,011.7	3,952.1	2,942.1	1,860.4	1,360.4	944.3	4,729.4	2,180.7	1,661.5	1,147.5	830.3	2,449.7	1,378.9	1,076.6	740.2	1,066.5	930.0	740.2	901.0	681.7	780.0
	Total Production Cost (cents/1,000 gal)	72.2	33.0	24.9	20.8	13.1	9.5	31.8	15.8	13.0	9.2	7.7	6.3	18.8	10.0	8.6	7.1	6.1	12.2	7.8	6.9	5.8	8.3	6.4	5.8	6.5	5.2	5.7
>1,000,000 517.491	Total Capital Cost (K$)	379,991	187,054	144,720	104,035	87,424	73,162	180,391	105,141	87,281	68,444	60,722	53,077	115,629	74,938	66,060	58,940	53,010	81,343	60,060	56,750	52,224	66,050	58,777	52,224	55,926	50,918	50,000
	O&M Cost (K$/year)	84,091.2	37,022.0	26,040.3	23,080.0	11,478.5	7,877.6	35,093.4	15,798.2	11,407.2	7,227.3	5,127.2	3,496.5	18,333.6	8,719.4	6,456.7	4,340.7	3,083.8	10,168.8	5,155.3	4,079.2	2,793.2	6,088.2	5,440.6	2,793.2	3,479.4	2,407.4	2,718.8
	Total Production Cost (cents/1,000 gal)	71.8	32.9	24.0	19.6	12.3	9.4	31.3	15.7	12.2	8.7	7.0	5.6	18.0	9.9	8.2	6.5	5.4	11.1	7.1	6.5	5.2	7.9	5.6	5.2	5.7	4.9	5.1

MGD= million gallons per day

Table 7-47. Estimated Cost for Removing p-Dichlorobenzene by Granular Activated Carbon Adsorption

System Size Population Range Average Daily Flow (MGD)		Influent				
		1,000 (ug/L)			500 (ug/L)	
		Effluent (ug/L)			Effluent (ug/L)	
		5	10	750	5	10
25-100	Total Capital Cost (K$)	13	13	13	13	13
0.013	O&M Cost (K$/year)	2.7	2.0	0.7	1.7	1.3
	Total Production Cost (cents/1,000 gal)	93.6	78.8	51.4	72.5	64.1
101-500	Total Capital Cost (K$)	24	24	24	24	24
0.037	O&M Cost (K$/year)	7.6	5.7	1.9	4.7	3.7
	Total Production Cost (cents/1,000 gal)	80.1	66.0	37.9	58.6	51.2
501-1,000	Total Capital Cost (K$)	48	48	48	48	48
0.093	O&M Cost (K$/year)	18.2	13.3	3.9	11.0	8.4
	Total Production Cost (cents/1,000 gal)	72.5	58.1	30.4	51.3	43.7
1,001-3,300	Total Capital Cost (K$)	78	78	78	78	78
0.280	O&M Cost (K$/year)	50.3	35.2	7.1	28.3	20.8
	Total Production Cost (cents/1,000 gal)	59.4	44.7	17.2	37.9	30.6
3,301-10,000	Total Capital Cost (K$)	236	236	236	236	236
0.952	O&M Cost (K$/year)	110.8	84.7	21.6	93.7	67.9
	Total Production Cost (cents/1,000 gal)	43.3	33.5	15.3	36.1	28.6
10,001-25,000	Total Capital Cost (K$)	815	815	815	815	815
2.753	O&M Cost (K$/year)	302.5	204.0	21.4	158.8	109.0
	Total Production Cost (cents/1,000 gal)	41.0	31.2	13.0	26.7	21.7
25,001-50,000	Total Capital Cost (K$)	4,065	3,641	1,553	1,553	1,553
6.065	O&M Cost (K$/year)	264.8	215.5	46.1	348.8	239.3
	Total Production Cost (cents/1,000 gal)	36.5	31.8	11.5	25.1	20.2
50,001-75,000	Total Capital Cost (K$)	5,583	5,018	2,234	4,701	4,278
11.680	O&M Cost (K$/year)	462.8	338.9	79.6	279.4	230.7
	Total Production Cost (cents/1,000 gal)	28.4	23.7	8.9	21.3	18.8
75,001-100,000	Total Capital Cost (K$)	6,374	5,726	2,538	5,363	4,879
15.912	O&M Cost (K$/year)	602.4	440.1	102.6	362.2	272.6
	Total Production Cost (cents/1,000 gal)	25.1	20.8	7.6	18.6	15.9
100,001-500,000	Total Capital Cost (K$)	10,680	9,744	5,137	9,220	8,519
36.806	O&M Cost (K$/year)	1,263.8	924.5	232.5	762.0	575.6
	Total Production Cost (cents/1,000 gal)	29.1	16.6	6.8	14.9	12.8
500,001-1,000,000	Total Capital Cost (K$)	30,102	24,053	12,232	22,707	18,106
129.421	O&M Cost (K$/year)	4,305.3	3,000.8	666.3	2,465.5	1,738.0
	Total Production Cost (cents/1,000 gal)	17.6	13.2	4.9	11.7	8.8
>1,000,000	Total Capital Cost (K$)	108,390	87,757	30,003	79,682	67,475
517.491	O&M Cost (K$/year)	16,678.2	11,634.6	2,210.7	9,390.8	6,753.2
	Total Production Cost (cents/1,000 gal)	16.5	12.4	4.7	10.6	8.4

MGD= million gallons per day

Table 7-40. Estimated Cost for Removing 1,1,1-Trichloroethane by Granular Activated Carbon Adsorption

System Size Population Range Average Daily Flow (MGD)		Influent						
		500 (ug/L)			200 (ug/L)		100 (ug/L)	
		Effluent (ug/L)			Effluent(ug/L)		Effluent(ug/L)	
		5	10	200	5	10	5	10
25-100	Total Capital Cost (K$)	13	13	13	13	13	13	13
0.013	O&M Cost (K$/year)	4.1	3.5	2.3	1.2	1.2	1.0	1.0
	Total Production Cost (cents/1,000 gal)	123.1	110.4	85.2	62.0	62.0	57.8	57.8
101-500	Total Capital Cost (K$)	24	24	24	24	24	24	24
0.037	O&M Cost (K$/year)	11.7	10.0	6.6	3.6	3.5	2.9	2.9
	Total Production Cost (cents/1,000 gal)	110.4	97.8	72.7	50.4	49.7	45.3	45.3
501-1,000	Total Capital Cost (K$)	48	48	48	48	48	48	48
0.093	O&M Cost (K$/year)	28.3	24.3	15.7	8.0	7.8	6.3	6.3
	Total Production Cost (cents/1,000 gal)	102.3	90.5	65.2	42.5	41.9	37.5	37.5
1,001-3,300	Total Capital Cost (K$)	78	78	78	78	78	78	78
0.280	O&M Cost (K$/year)	80.7	68.4	42.6	19.3	18.9	14.4	14.2
	Total Production Cost (cents/1,000 gal)	89.2	77.1	51.9	29.1	28.7	24.3	24.1
3,301-10,000	Total Capital Cost (K$)	236	236	236	236	236	236	236
0.952	O&M Cost (K$/year)	187.7	159.9	101.4	63.0	61.7	46.3	45.8
	Total Production Cost (cents/1,000 gal)	63.1	55.1	38.3	27.2	26.8	22.4	22.3
10,001-25,000	Total Capital Cost (K$)	3,055	2.884	815	815	815	815	815
2.753	O&M Cost (K$/year)	224.3	193.8	252.2	99.5	97.0	67.3	66.3
	Total Production Cost (cents/1,000 gal)	63.0	57.7	36.0	20.8	20.5	17.6	17.5
25,001-50,000	Total Capital Cost (K$)	4,721	4,479	3,861	1,553	1,553	1,553	1,553
6.065	O&M Cost (K$/year)	397.9	345.3	229.6	218.2	212.7	147.4	145.2
	Total Production Cost (cents/1,000 gal)	46.5	42.7	33.7	19.2	19.0	16.1	16.0
50,001-75,000	Total Capital Cost (K$)	6,458	6,136	5,311	2,234	2,234	2,234	2,234
11.680	O&M Cost (K$/year)	699.0	605.6	400.4	411.0	400.4	274.6	270.4
	Total Production Cost (cents/1,000 gal)	36.7	33.5	26.1	16.7	16.4	13.5	13.4
75,001-100,000	Total Capital Cost (K$)	7,376	7,007	6,063	4,770	4,740	2,538	2,538
15.912	O&M Cost (K$/year)	912.4	789.8	520.7	278.9	273.4	368.3	362.5
	Total Production Cost (cents/1,000 gal)	32.7	29.8	22.9	15.8	15.6	12.2	12.1
100,001-500,000	Total Capital Cost (K$)	12,128	11,595	10,230	8,362	8,319	7,741	7,719
36.806	O&M Cost (K$/year)	1,914.2	1,656.6	1,092.8	538.5	528.7	409.2	405.0
	Total Production Cost (cents/1,000 gal)	26.3	23.9	18.3	12.3	12.2	10.8	10.7
500,001-1,000,000	Total Capital Cost (K$)	38,732	33,049	25,300	17,834	17,759	16,755	16,716
129.421	O&M Cost (K$/year)	6,769.7	5,663.5	3,555.7	1,626.0	1,596.3	1,236.2	1,223.6
	Total Production Cost (cents/1,000 gal)	25.3	21.4	14.7	8.5	8.4	7.4	7.3
>1,000,000	Total Capital Cost (K$)	146,018	130,924	96,052	66,545	66,290	59,718	59,612
517.491	O&M Cost (K$/year)	26,675.3	22,650.4	14,008.9	6,319.0	6,203.8	4,668.1	4,621.6
	Total Production Cost (cents/1,000 gal)	24.5	21.3	14.2	8.1	8.0	6.7	6.7

MGD= million gallons per day

Table 7-49. Assumption for Updating O&M Costs for Multiple-Tray Aeration Towers

Cost Category	Cost	Assumption
Labor ($/hr)	4.55 11.00	Size Category <150,000 Size Category >150,000
Energy ($/kwhr)	0.07	
Weighted Construction Cost Index	318.2	August 1983
Producer Price Index	285.1	August 1983

Table 7-50. Multiple-Tray Aeration Design Parameters

System Size Population Range Average Daily Flow (MGD)	Area of Aerator (sq ft)	Depth of Aerator (ft)	Number of Units	Volume of Each Unit (cubic ft)
25-100 0.013	4.00	5.0	1	20
101-500 0.037	5.00	5.0	1	25
501-1,000 0.093	4.00	8.0	1	32
1,001-3.300 0.280	6.00	10.0	1	60
3.301-10,000 0.952	18.75	16.0	1	300
10,001-25,000 2.753	20.00	16.0	2	320
25,001-50,000 6.065	30.00	16.0	3	480
50,001-75,000 11.680	40.00	16.0	4	640
75,001-100,000 15.912	60.00	16.0	4	960
100,001-500,000 36.806	130.00	16.0	4	2,080
500,001-1,000,000 129.421	200.00	16.0	9	3.200
>1,000,000 517.491	200.00	16.0	36	3.200

MGD=million gallons per day

* Amortized at 12 percent for 20 years.

Note: Assumed 50 Percent Removal Efficiency

Table 7-51. Estimated Costs for Multiple-Tray Aeration Towers

System Size Population Range Average Daily Flow (MGD)	Total Capital Cost $	Amortized* Total Capital Cost ($/Year)	Operations & Maintenance Cost ($/Year)	Total Production Cost (cents/1,000 gal)
25-100 0.013	4,500	600	140	15.60
101-500 0.037	5,300	710	170	6.52
501-1,000 0.093	6,300	840	190	3.03
1,001-3,300 0.280	9,900	1,300	350	1.61
3,301-10,000 0.952	31,500	4,200	950	1.48
10,001-25,000 2.753	66,000	8,800	1,980	1.07
25,001-50,000 6.065	132,000	18,000	3,800	0.98
50,001-75,000 11.680	217,000	29,000	6,100	0.82
75,001-100,000 15.912	291,000	39,000	7,900	0.81
100,001-500,000 36.806	508,000	68,000	12,800	0.60
500,001-1,000,000 129.421	1,557,000	208,000	37,600	0.52
>1,000,000 517.491	6,230,000	834,000	150,300	0.52

MGD=million gallons per day
* Amortized at 12 percent for 20 years.
Note: Assumed 50 Percent Removal Efficiency

Table 7-52. O&M Cost Parameters for Multiple-Tray Aeration Towers

USRT Range (ft^3)	K_1	b	c	d	e
680-6,400	31.36	0.625	0.373	0.286	0.225

Source: EPA, 1982a.

Table 7-53. Diffused Aeration--Cost Summary

System Size Population Range Average Daily Flow	Capital Cost Total ($K)	Capital Cost Annual* ($K/yr)	O & M Costs ($K/yr)	Total Costs ($K/yr)	Total Costs (c/1,000 gal)
25-100 0.013	1.12	0.15	0.55	0.70	14.7
101-500 0.037	1.81	0.24	1.28	1.52	11.3
501-1,000 0.093	2.87	0.38	2.83	3.21	9.5
1,001-3,300 0.280	7.98	1.07	7.87	8.94	8.7
3,301-10,000 0.952	24.55	3.29	21.39	24.68	7.1
10,001-25,000 2.753	60.74	8.13	55.26	63.39	6.3
25,001-50,000 6.065	112.60	15.07	111.30	126.37	5.7
50,001-75,000 11.680	201.46	26.97	205.78	232.75	5.5
75,001-100,000 15.912	266.61	35.69	275.71	311.40	5.4
100,001-500,000 36.806	571.82	76.56	609.30	685.86	5.1
500,001-1,000,000 129.421	1,803.68	241.48	2,040.14	2,281.62	4.8
>1,000,000 517.491	6,208.92	831.25	7,824.71	8,655.96	4.6

MGD=Million Gallons Per Day
* Amortized at 12% , 20 yrs.
Note: Assume 50 Percent Removal Efficiency

Table 7-54. Estimated Costs for Powdered Activated Carbon

System Size Population Range Average Daily Flow (MGD)	Capital Cost		Operation and Maintenance Cost	
	Total (K$)	Annual (K$/yr)	(K$/yr)	(c/1,000 gal)
25-100 0.013	NA	NA	NA	NA
101-500 0.037	NA	NA	NA	NA
501-1,000 0.093	NA	NA	NA	NA
1,001-3,300 0.280	NA	NA	NA	NA
3,301-10,000 0.952	0	0	24.9	7.2
10,001-25,000 2.753	0	0	72.1	7.2
25,001-50,000 6.065	0	0	159.8	7.2
50,001-75,000 11.680	0	0	305.8	7.2
75,000-100,000 15.912	0	0	416.6	7.2
100,001-500,000 36.806	0	0	963.6	7.2
500,001-1,000,000 129.421	0	0	3388.1	7.2
>1,000,000 517.491	0	0	13547.5	7.2

MGD= million gallons per day
NA = Not Applicable
(c/1,000 gals) = cents/1,000 gals
Note : 1. PAC Dose(mg/L) = 20
2. PAC Cost($/lb) = 0.43
3. Assumed Removal Efficiency = 25 Percent

Table 7-55. Wellfield Management Cost Summary

System Size Population Range Average Daily Flow (MGD)	Capital Cost		O & M Cost	TOTAL COST	
	Total (K$)	Annual (K$/yr)	(K$/yr)	(K$/yr)	(c/1000 gals)
25-100 0.013	NA	NA	NA	NA	NA
101-500 0.037	NA	NA	NA	NA	NA
501-1,000 0.093	NA	NA	NA	NA	NA
1,001-3,300 0.280	NA	NA	NA	NA	NA
3,301-10,000 0.952	10.5	1.4	1.7	3.1	0.9
10,001-25,000 2.753	31.8	4.3	4.6	8.9	0.9
25,001-50,000 6.065	49.0	6.6	10.6	17.2	0.8
50,001-75,000 11.680	91.9	12.3	20.3	32.9	0.8
75,000-100,000 15.912	137.8	18.5	27.8	46.2	0.8
100,001-500,000 36.806	373.3	50.0	64.1	114.1	0.9
500,001-1,000,000 129.421	1,998.1	267.5	220.0	487.5	1.0
>1,000,000 517.491	7,992.5	1,070.0	874.1	1,944.1	1.0

MGD= million gallons per day
NA - Not Applicable
c/1,000 gals - cents per 1,000 gals

Table 7-56. Regionalization Summary of Costs
(Pipeline Lengths = 7.5 and 10.5 miles)

System Size Population Range Average Daily Flow (MGD)	Capital Cost		O & M Cost	TOTAL COST	
	Total (K$)	Annual (K$/yr)	(K$/yr)	(K$/yr)	($/K gals)
7.5 MILES :					
25-100 0.013	436.3	58.4	0.16	58.6	12.34
101-500 0.037	652.9	87.4	0.43	87.8	6.50
501-1,000 0.093	853.2	114.2	1.00	115.2	3.39
1,001-3,300 0.280	1,001.0	134.0	3.56	137.6	1.35
3,301-10,000 0.952	1,428.7	191.3	12.69	204	0.59
10.5 MILES :					
25-100 0.013	573.4	76.8	0.17	76.9	16.21
101-500 0.037	860.4	115.2	0.46	115.6	8.56
501-1,000 0.093	1,124.9	150.6	1.06	151.7	4.47
1,001-3,300 0.280	1,317.3	176.4	3.92	180.3	1.76
3,301-10,000 0.952	1,878.6	251.5	14.31	265.8	0.76

MGD= million gallons per day
$/K gals = Dollars per 1,000 gallons

Table 7-57. Bottled Water Costs

System Size Population Range Average Daily Flow (MGD)	Total Capital Cost K$	Amortized* Total Capital Cost (K$/Year)	O&M Cost (K$/Year)	Total Production Cost	
				(K$/yr)	(c/1,000 gal)
25-100 0.013	1.29	0.17	5	5.17	109
101-500 0.037	3.23	0.43	12	12.43	92
501-1,000 0.093	8.08	1.08	33	34.08	100
1,001-3,300 0.280	20.20	2.70	90	92.70	91
3,301-10,000 0.952	65.00	8.70	300	308.70	89

MGD=million gallons per day
# 100 percent of Households Receiving Bottled Water
* Amortized at 12 percent for 20 years.
Source: EPA,1984c

Table 7-58. Assumptions Used in Development of Alternate Source Costs for Ground Water Supplies

	System Size											
gpm	10	25	65	195	660	1,910	4,210	8,106	11,043	25,543	89,818	359,139
MGD	0.013	0.037	0.093	0.280	0.952	2.753	6.065	11.680	15.912	36.806	129.421	517.491
Total No. of System Wells	1	2	2	3	4	6	8	16	17	42	128	206
Groups of Wells	1	1	1	1	1	2	2	4	4	7	40	1
No. of Wells To Be Replaced	1	2	2	3	4	3	4	4	4	6	12	20
Distance To Replacement Wells (miles)	0.5	1.0	1.5	2	2.5	3	3.5	5	5	5	7	7
Well Size (inches)	4	4	6	8	10	12	16	16	16	16	16	24
Well Capacity (gpm)	10	25	65	100	220	475	700	675	920	910	840	1,950
No. of Wells at Rest	0	1	1	1	1	1	1	1	1	2	2	2

Table 7-59. Assumptions Used in Development of Alternate Source Costs for Surface Water Supplies

	System Size											
gpm	10	25	65	195	660	1,910	4,210	8,106	11,043	25,543	89,818	359,139
MGD	0.013	0.037	0.093	0.280	0.952	2.753	6.065	11.680	15.912	36.806	129.421	517.491
Percent of Supply Affected by VOC Contamination	100	100	100	100	100	50	50	25	25	14	10	10
No. of Wells To Be Constructed	1	2	2	3	4	3	4	4	4	6	12	20
Distance To Wells (miles)	0.5	1.0	1.5	2	2.5	3	3.5	5	5	5	7	7
Well Size (inches)	4	4	6	8	10	12	16	16	16	16	16	24
Well Capacity (gpm)	10	25	65	100	220	475	700	675	920	910	840	1,950
No. of Wells at Rest	0	1	1	1	1	1	1	1	1	2	2	2

Table 7-60. Alternate Source Summary of Costs

System Size Population Range Average Daily Flow (MGD)	Capital Cost (GW & SW)		O & M Cost		TOTAL COST			
	Total (K$)	Annual ($/yr)	GW (K$/yr)	SW (K$/yr)	GW (K$/yr)	GW (c/k gals)	SW (K$/yr)	SW (c/k gals)
25-100 0.013	34.5	4.6	0.0	0.2	4.6	96.9	4.8	101.2
101-500 0.037	86.9	11.6	0.1	0.5	11.7	86.6	12.1	89.6
501-1,000 0.093	157.7	21.1	0.4	1.5	21.5	63.3	22.6	66.6
1,001-3,300 0.280	320.0	42.8	1.7	5.0	44.5	43.5	47.8	46.8
3,301-10,000 0.952	613.9	82.2	4.9	16.2	87.1	25.1	98.4	28.3
10,001-25,000 2.753	750.6	100.5	7.3	25.0	107.8	10.7	125.5	12.5
25,001-50,000 6.065	1,368.1	183.2	15.8	57.7	199.0	9.0	240.9	10.9
50,001-75,000 11.680	1,503.9	201.3	16.3	56.4	217.6	5.1	257.7	6.0
75,000-100,000 15.912	2,389.4	319.9	17.6	75.9	337.5	5.8	395.8	6.8
100,001-500,000 36.806	2,603.9	348.6	34.4	111.4	383.0	2.9	460.0	3.4
500,001-1,000,000 129.421	6,056.7	810.9	68.0	242.2	878.9	1.9	1,053.1	2.2
>1,000,000 517.491	21,038.1	2,816.6	397.3	1,350.2	3,213.9	1.7	4,166.8	2.2

GW = Ground Water Systems
SW = Surface Water Systems
MGD= million gallons per day
(c/K gals) = cents/ 1000 gals

Note : Surface water systems O&M cost greater due to energy costs required to withdraw water from wells. No such cost incurred for ground water systems.

Table 7-61. Manufacturer's Cost Data--Point-of-Use Carbon Adsorption Devices

Unit	Approximate Installed Cost ($)	Replacement Cartridge Cost ($)	Approximate Weight of Carbon (lb)
i	398.00	98.50	0.92
2	275.00	50.00	7.50
3	299.00	33.00	3.75
4	340.00	60.00	1.69
5	298.95	44.95	0.66
Average	325.00	60.00	3.0

Table 7-62. Estimated Costs for Point-of-Use Carbon Units

Population (Average Daily Flow)	Number of Units (Households)	Total Capital Costs ($)	O&M Costs ($/year)	
			Benzene, 1,2-Dichloroethane or Multiple Occurrence Case (4-month replacement frequency)	All Other Singular VOCs (8-month replacement frequency)
25 - 100 (13,000 gpd)	30	9,750	5,400	2,700
101 - 500 (37,000 gpd)	100	32,500	18,000	9,000

gpd = gallons per day.

Table 7-63. Manufacturer's Cost Data--Point-of-Entry Carbon Adsorption Units

Unit	Approximate Installed Cost ($)	Replacement Cartridge Cost ($)	Approximate Weight of Carbon (lb)
1	900.00	250.00	27
2	1,400.00	300.00	36
3	2,000.00	400.00	63
Average	1,500.00	350.00	40

Table 7-64. Estimated Costs for Point-of-Entry Carbon Units

Population (Average Daily Flow)	Number of Units (Households)	Total Capital Costs ($)	O&M Costs ($/year)	
			Benzene, 1,2-Dichloroethane or Multiple Occurrence Case (4-month replacement frequency)	All Other Singular VOCs (8-month replacement frequency)
25 - 100 (13,000 gpd)	30	45,000	31,500	15,750
101 - 500 (37,000 gpd)	100	150,000	105,000	52,500

gpd = gallons per day.

Table 7-65. Manufacturer's RO Point-of-Use Cost Data

Unit	Installed Cost ($)	Replacement Prefilter Cost ($/yr)	Carbon Filter Replacement Cost ($/yr)	RO Membrane Replacement ($/yr)
1	699	10.00	20.00	31.22
2	550	18.00	19.50	47.50
3	550	8.00	8.00	55.00
4	680	10.00	20.00	36.52
Average	620	11.50	17.00	42.60

Table 7-66. Estimated Costs for Point-of-Use RO Units

Population (Average Daily Flow)	Number of Units (Households)	Total Capital Costs ($1,000)	O&M Costs (K$/yr)
25 - 100 (13,000 gpd)	30	18.6	2.13
101 - 150 (37,000 gpd)	100	62.0	7.11

gpd = gallons per day.

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Table A-1. Efficiencies of VOC Removal Technologies

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
Packed Tower Aeration	1,500-2,000	97-99	Wurtsmith Air Force Base, Michigan. Full-scale aeration system constructed to remove TCE from a contaminated aquifer. Maximum flow rate and surface loading rate, respectively, are 600 gpm and 31 gpm/ft^2. Air-to-water ratio of 25:1 using a 2,000-cfm blower.	United States Air Force Engineering & Services Center, 1982
	1.6-130	>90	Tacoma, Washington. Drinking water wells contaminated with TCE, tetrachloroethylene, 1,1,2,2-tetrachloroethane, and trans-1,2-dichloroethylene. Treated up to 3,500 gpm of contaminated water. Air-to-water ratio of 300:1; 1,1,2,2-tetrachloroethane (most difficult contaminant to remove) was reduced by 90 percent; >90 percent removal for the remaining contaminants.	Nadeau et al., 1983
	130	97	Warrington, Pennsylvania. Potable water supply wells contaminated with TCE. Flow rate of 200-225 gpm and an air-to-water ratio of 40:1, reduced TCE influent concentration to 3.5 ug/L.	

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 2 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
Packed Tower Aeration (Continued)	3,000-14,000	97.9->99.99	Norristown, Pennsylvania. TCE contamination. Three packed tower aeration systems constructed for decontamination of an aquifer. Air-to-water ratio 72:1, a removal efficiency of approximately 99.7 was achieved in the first tower. Air-to-water ratio of 175:1, >99.99 percent removal efficiency was achieved in the second tower. Air-to-water ratio 85:1, a removal efficiency of approximately 97.9 was achieved in the third tower.	Superior Tube Company, 1982
	50-220	96.8-99.4	Rockaway Township, New Jersey. Ground water contaminated with TCE and ethers. The tower removed virtually all of the contaminant at an air-to-water ratio of about 144:1. Diisopropyl ether was reduced from 47.0 to 0.3 ug/L (99.4 percent) while methyl tertiary butyl ether was reduced from 37.5 to 1.2 ug/L (96.8 percent).	Journal AWWA, 1982 Journal AWWA, 1981
GAC	120-276	>99	New Hampshire. Ground water contaminated with TCE. Filtrasorb® 400 adsorption columns (EBCT = 9 min) reduced influent concentration to below detection limit (0.1 ug/L) during 18 months of operation.	Love et al., 1983 Love and Eilers, 1982

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 3 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
GAC (Continued)	0-214	>99	Connecticut. Ground water contaminated with 1,1,1-trichloroethane and TCE. Filtrasorb® 400 adsorption columns (EBCT = 8.5 min) reduced influent concentrations of 1,1,1-trichloroethane (12 - 214 ug/L) and TCE (0-10 ug/L) to below detection limits during the first 12 weeks and 12 months of operation, respectively.	Love *et al.*, 1983 Love and Eilers, 1982
	23	>99	New Jersey. Ground water contaminated with 1,1,1-trichloroethane. Aerated water processed through GAC (Witcarb 950) columns (EBCT = 18 min). No detectable VOC found during 58 weeks of operation.	Love *et al.*, 1983 Love and Eilers, 1982
	20-130	78-97	North Penn Water Authority, Pennsylvania. GAC system of two 5-foot-diameter vessels and approximately 14 ft high with 10-ft straight sidewalls reduced ground water TCE influent concentration to 4.5 ug/L for 2 months after installation.	North Penn Water Authority, 1982

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 4 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
GAC (Continued)	50-220	>99	Rockaway Township, New Jersey. Ground water contaminated with TCE, methylene chloride, diisopropyl ether, and methyl tertiary butyl ether. Two GAC adsorption tanks processed approximately 1 MGD water and reduced influent concentration of TCE and other organic pollutants to less than 1 ug/L during first 1-1/2 months of operation.	Hess *et al.*, 1981 JAWWA, 1981 Industrial Waste Engineering, 1981
Multiple-Tray Aeration	20-70	50-85	Smyrna, Delaware. Ground water contaminated with TCE. Hydraulic loading varied from 65-100 pecent of design flow and resulted in 50-85 percent removal of TCE.	Joyce, 1980
	6.7-35.0	approximately 11-approximately 85	Camden, New Jersey. Ground water contaminated predominantly with TCE and tetrachloroethylene. A 12-ft-high slat-tray aerator (cross-sectional area = 80 ft^2) was constructed. At an air-to-water ratio of 30:1, performance data indicated influent concentrations of TCE (13.1-35.0 ug/L) and tetrachloroethylene (6.7-19.4 ug/L) could be reduced by 11-61 percent and 30-85 percent, respectively.	Hess *et al.*, 1981
	50-200	50-60	Norwalk, Connecticut. TCE was the predominant contaminant in a water well field. A 50-60 percent TCE removal was achieved using a 20-ft-high multiple-tray unit (cross-sectional area = 200 ft^2) equipped with two 9,300-cfm blowers.	Hess *et al.*, 1981

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 5 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
Diffused Aeration	70-300	90-92	Bristol Borough, Pennsylvania. Diffusers were installed near the bottom of a 12-ft-deep chlorine contact chamber with a 20-min detention time at a 2-MGD flow rate. At an air-to-water ratio of approximately 3.5:1, the diffused aeration system reduced the combined influent concentration of TCE (70-100 ug/L) and tetrachloroethylene (200-300 ug/L) to a total VOC effluent concentration of 10-12 ug/L.	Bristol Borough Water and Sewer Authority, 1982
	3.7-171	58-91	Glen Cove, New York. Diffused aeration pilot study conducted to remove TCE, tetrachloroethylene, and 1,1,1-trichloroethane. Higher percent removal resulted from an air/water ratio of 15:1. Average, influent concentrations of TCE (171 ug/L), tetrachloroethylene (49 ug/L) and 1,1,1-trichloroethane (3.7 ug/L) were reduced by 87 percent, 91 percent, and 81 percent, respectively.	Ruggiero et al., 1980 Nebolsine Kohlmann Ruggiero Engineers, 1982

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 6 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
Diffused Aeration (Continued)	17-1,064	up to >99.9	Cincinnati, Ohio. Pilot study conducted to remove TCE and tetrachloroethylene spiked into Cincinnati tap water. Various air-to-water ratios ranging from 1:1 to 20:1 were evaluated to reduce influent concentrations of TCE (73-1,064 ug/L) and tetrachloroethylene (17-1,025 ug/L). Both VOCs were almost entirely removed at air-to-water ratios of 16:1 and 20:1.	Love and Eilers, 1982
	1.4-237	42-90	New Jersey. Solvent-contaminated ground water was processed through a 4-ft-high and 1.5-inch-diameter diffused-air aeration system at an air-to-water ratio of 4:1. Average influent concentrations of 1,1,1-trichloroethane (237 ug/L), tetrachloroethylene (94 ug/L), TCE (3 ug/L), and 1,2-dichloroethane (1.4 ug/L) were reduced to 23, 9, 0.4, and 0.8 ug/L, respectively.	Love and Eilers, 1982
Spray Aeration	100-200	>99.9	Southern Florida. Aquifer contaminated with 1,1-dichloroethane, TCE, tetrachloroethylene, vinyl chloride, and 1,1,1-trichloroethane. A 4-stage aeration system with 20 spray heads per stage and 10-psi pressure drop through the spray heads removed more than 99.9 percent of total influent VOC concentration.	

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 7 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
Spray Aeration (Continued)	—	50-70	A United States water facility water contaminated with TCE. A 10-cm pipe grid with spray nozzles was installed inside the top of a storage reservoir and achieved 50-70 percent TCE removal.	Robeck and Love, 1982
PAC	approximately 70	25	Cincinnati, Ohio. Untreated CCl_4-contaminated Ohio River water dosed with varying PAC amounts. Jar test revealed, after 1-min rapid mixing and 1-hr slow mixing, only 25 percent CCl_4 reduction achieved with the highest PAC dose of 30 mg/L.	Lykins and DeMarco, 1981
	12	25	Evansville, Indiana. Using conventional treatment and an average PAC dose of 8 mg/L, an average of 25 percent reduction in CCl_4 concentration was achieved.	Rexing, 1978 (cited by Lykins and DeMarco)
	10-24	40-65	North Miami Beach, Florida. Plant-scale studies conducted in a conventional lime softening plant which treated Biscayne Aquifer water contaminated with synthetic organics. Influent concentration of 10-24 ug/L of 1,1,1-trichloroethane was reduced by 40-65 percent using 7 mg/L of PAC.	ESE, 1979

Table A-1. Efficiencies of VOC Removal Technologies (Continued, Page 8 of 8)

Treatment Technology	Influent Concentration (ug/L)	Percent VOC Removal Efficiency	Comments	References
Home Carbon Adsorption Units	20-50	40-99	New Orleans, Louisiana. Ten models of activated carbon home treatment units with different rated capacities were evaluated. Test water was an artesian well water spiked with 1,1,1-trichloroethane, carbon tetrachloride, TCE, and tetrachloroethylene at target levels of 50, 20, 50, and 50 ug/L, respectively. At least one model from each of the four basic configurations removed 76-99 percent of the spiked VOC. Carbon tetrachloride and 1,1,1-trichloroethane broke through the carbon filter first. TCE and tetrachloroethylene did not break through at all in some units.	Perry _et al._, 1981

B.1 GRANULAR ACTIVATED CARBON ADSORPTION EXAMPLE COST CALCULATION

B.1.1 Carbon Contactor Capital and Operation and Maintenance (O&M) Costs

The following is an example calculation illustrating the methodology used to determine the total capital costs and O&M costs to remove 1,2-dichloroethane from an initial concentration of 200 micrograms per liter (ug/L) to 5 ug/L. Assume a plant flow rate of 6.065 MGD. First calculate the total contactor volume (based on a 10-minute empty-bed contact time):

$$6.065 \times 10^6 \text{ gallons per day (gpd)} \times 10 \text{ min} \times \frac{1 \text{ day}}{1{,}440 \text{ min}}$$

$$\times \frac{1 \text{ ft}^3}{7.48052 \text{ gal}} = 5{,}630 \text{ ft}^3$$

$5{,}630 \text{ ft}^3$ = Total contactor volume

Assume 4 contactors each with a volume of $1{,}407.5 \text{ ft}^3$.

$$CC = K_2 \, USRT_c{}^{l} \, CCI^m \, UN^n$$

Where:
$K_2 = 472.15$
$USRT_c = 1{,}407.5 \text{ ft}^3$
$l = 0.382$
$CCI = 331.8/100$
$m = 1$
$UN = 4$, and
$n = 1$

$$CC = 472.15\,(1{,}407.5)^{.382}\,(331.8/100)^1(4) = \$99{,}936/\text{yr}.$$

This construction cost does not include cost for backwash pumps. Assume 18 gallons per minute per square foot (gpm/ft^2) backwash pump capacity. The area of each filter is 176 ft^2 based on an 8-ft bed depth.

$$\text{Backwash pump capacity} = 176 \text{ ft}^2 \times 18 \text{ gpm/ft}^2$$
$$= 3{,}170 \text{ gpm}$$

Next calculate the cost of backwash pump:

$$CC = K_2 \ USRT_c{}^{l} \ CCI^{m} \ UN^{n}$$

Where: $K_2 = 29.95$

$USRT_c = 3{,}170$ gpm

$l = 0.590$

$CCI = 300/100$

$m = .966$

$UN = 1$, and

$n = 1$

$$CC = 29.95 \ (3{,}170)^{.590} \ (300/100)^{.966} (1)^{1} = \$10{,}067/\text{yr}$$

Adding the capital cost for contactors and backwash pump:

$99,936/yr + $10,067/yr = $110,003/yr

Converting to Present Worth (PW):

PW = CC x (P/A, 8%, 20 yr) P/A = 9.81815

PW = $110,003 x 9.81815 = $1,080,026

Adding additional construction cost yields:

a. Contingency (15% PW) = 0.15 (1,083,343) = $ 162,004

b. Contractor's overhead and profit (12% PW) = 0.12 (1,080,026) = 129,603

c. Engineering fees [15%(1.12 PW)] = 0.15(1,080,026 + 129,603) = 181,444

Total Capital Cost = $1,553,077

Amortizing over 20 years at 12 percent yields:

Annual Cost = PW(A/P, 12%, 20 yr) A/P = 0.13388

Annual Cost = 1,553,077 x .13388 = $ 208,000

Next calculate the O&M costs for the contactors.

Using the component quality (CQ) method, a USRT of 176 ft^2, and the empirical constants described in Section 4.2:

Process Energy

$CQ = 4.85(176)^{1.0005}(4) = 3,423.24$ kwh/yr

Maintenance Material

$CQ = 31.33(176)^{.683}(4) = \$4,283/yr$

Labor

$CQ = 9.87(176)^{.712}(4) = 1,567.4$ hr/yr

Building Energy

$CQ = 408.15(176)^{.882}(4) = 156,106.85$ kwh/yr

Applying the energy and labor cost assumptions shown in Table 7-1:

Energy

(3,423.24 + 156,106.84) kwh/yr x $0.07/kwh = $11,167/yr

Labor

1,567.4 hr/yr x $11.00/hr = $17,241/yr

Updating the maintenance material cost to August 1983 Dollars:

Maintenance Material

$$4,283 \times \frac{\text{PPI August 1983}}{\text{PPI Dec. 1980}} \frac{285.1}{200} = \$6,125 \text{ yr}$$

Total O&M costs excluding carbon:

$11,167 + $17,241 + $6,125 = $34,533/yr

B.1.2 Annual Carbon Costs

To estimate the annual carbon costs first find the estimated carbon usage rate for 1,2-dichloroethane for the given influent and effluent concentrations in Table 7-36. At an influent concentration of 200 ug/L and effluent concentration of 5 ug/L, this usage rate is estimated to be 0.616 lb GAC/1,000 gallons of water treated. Convert this to a daily usage rate:

$$\frac{0.616 \text{ lb}}{1{,}000 \text{ gal}} \times \frac{6.065 \times 10^6 \text{ gallons per day (gpd)}}{1{,}000 \text{ gal}} = 3{,}736 \text{ lb/day}$$

Since this usage rate is in excess of 2,000 lb/day, a reactivation facility must be installed at the site.

Reactivation Facility Capital Cost--Assuming a 40 percent downtime and a 40 lb/day/ft^2 hearth loading rate:

$$\text{Reactivation Facility Size} = \frac{3{,}736 \text{ lb/day}}{40 \text{ lb/day/ft}^2 \times 0.6} = 160 \text{ ft}^2$$

$$CC = K_2 USRT^l \; CCI^m \; UN^n$$

Where:

$K_2 = 6{,}047$

$USRT = 160 \text{ ft}^2$

$l = 439$

$CCI = 329.6/100$

$m = 1.006$

$UN = 1$

$n = 1.002$

$$CC = 6{,}047(160)^{.439}(329.6/100)^{1.006}(1)^{1.002}$$

$$CC = \$186{,}313/\text{yr}$$

Converting to PW:

PW = CC x (P/A, 8%, 20 yr)   P/A = 9.81815

PW = $186,313 x 9.81815

PW = $1,829,249

PW = $1,829,249

Adding additional construction cost yields:

a. Contingency (15% PW) = 0.15(1,829,249) = 274,387

b. Contractor's overhead and profit (12% PW) = 0.12(1,829,249) = 219,510

c. Engineering fees [15%(1.12 PW)] = 0.15(1,829,249 + 219,510) = 307,313

d. Total PW $2,630,459

Amortizing over 20 years at 12 percent yields:

Annual Cost = PW(A/P, 12%, 20 yr) x $2,630,459

Annual Cost = $352,166/yr

Annual Cost = $352,200/yr

Reactivation Facility O&M Costs--The equation used to estimate the O&M costs for the reactivation facility is as follows:

$$OM = K_1 USRT_o^b PR^c PPI^d DHR^e NTG^f DSL^g UN^h$$

Where: K_1 = 41,630.3

$USRT_o$ = 160 ft^2

b = 0.809

PR = $0.07/kwh

c = 0.045

PPI = 285/100

d = 1

DHR = $11.00/hr

e = 0.280

$NTG = \$0.004/scf$

$f = 0.581$

$UN = 1$

$n = 1.002$

Correcting the above equation to reflect 40 percent downtime yields:

$$OM = 41{,}630.3(160)^{0.809}(0.6)(0.07)^{0.045}(285/100)^{1}$$
$$(11.0)^{0.280}(0.6)(0.004)^{.581}(1)^{1.002}$$
$$OM = \$182{,}015/yr$$

Carbon Replacement Cost--Assuming a 10 percent carbon loss per reactivation cycle, the additional O&M costs are:

3,763 lb/day x 10% x 365 days/year =

137,350 lb GAC make up per year

Assuming a carbon cost of $0.50/lb:

137,350 lb x $0.50/lb = $68,675/yr

B.1.3 Total Capital Costs and O&M Costs

The following is an itemized list of all capital cost factors and O&M costs:

Total Capital Costs--

Capital Cost (Contactor) = $1,553,000

Capital Cost (Reactivation Facility) = 2,630,000

Total Capital Costs = $4,183,000

Annual Cost = $4,183,000 x (A/P, 12%, 20 yr)   A/P = 0.13388

Annual Cost = $4,183,000 x 0.13388 = $560,000/yr

Total O&M Costs--

O&M Cost (Contactor) = $ 34,533
O&M Cost (Reactivation Facility) = 182,015
O&M Cost (10% Carbon Make up) = 68,675

Total O&M Costs = $285,223

B.1.4 Total Production Cost

To determine the total production cost, add the total yearly cost and divide by the yearly flow:

Amortized total capital cost = 560,000
Total O&M Costs = 285,230

Total Yearly Cost = $845,223

$$\text{Total Yearly Flow} = 6.065 \times 10^6 \text{gpd} \times \frac{365 \text{ days}}{\text{year}} \quad \frac{1}{1{,}000 \text{ gal}}$$

$$= 2.214 \times 10^6 \; (1{,}000 \text{ gal/year})$$

$$\text{Total Production Cost} = \frac{\$845{,}223/\text{yr} \times \left(\frac{100 \text{ Cents}}{\text{Dollar}}\right)}{2.214 \times 10^6 \; (1{,}000 \text{ gal/yr})}$$

$$= 38 \text{ cents/1,000 gallons}$$

B.2 MULTIPLE-TRAY AERATION EXAMPLE COST CALCULATION

The procedure used to determine the total capital costs and O&M costs is illustrated in the following example. Consider a multiple-tray aeration system for a population range of 50,001 to 75,000 and average flow of 11.680 MGD.

First, determine the total area required based on 50 gpm/ft^2:

$$A = 11.680 \times 10^6 \text{ gpd} \times 6.94 \times 10^{-4} \text{ days/min} \div 50 \text{ gpm/ft}^2$$

$$A = 162 \text{ ft}^2$$

Assume four units of 40 ft^2/unit:

$$\text{Volume of each unit} = 40 \text{ ft}^2 \times 16 \text{ ft} = 640 \text{ ft}^3$$

Equation 1 from Section 7.2.1 is used to determine the construction costs:

$$CC = 11.59(640)^{0.7199} \left(\frac{318.2}{100}\right)^{0.9965} (4) = \$15,390/\text{yr}$$

This construction cost is amortized at 8 percent for 20 years. Converting the capital cost to a Present Worth (PW) cost yields:

$PW = CC \times (P/A, 8\%, 20 \text{ yr}) \qquad P/A = 9.81815$

$PW = 15,390 \times 9.81815$ = \$151,100

Adding additional construction costs yields:

a.	Contingency (15% PW) = 0.15(151,100)	= \$ 22,700
b.	Contractor's overhead and profit (12% PW) = 0.12(151,100)	= 18,100
c.	Engineering fees [15%(1.12 PW)] 0.15(151,000 + 18,100)	= 25,400
d.	Total PW	= \$217,300

Amortizing over 20 years at 12 percent yields:

$$\text{Annual Cost} = PW(A/P, 12\%, 20 \text{ yr}) = \$217,300(0.13388)$$

$$\text{Annual Cost} = \$29,100/\text{yr}$$

Equation 2 from Section 7.2.1 is used to determine the O&M costs:

$$OM = 31.36(640)^{0.625}(0.07)^{0.373}\left(\frac{285.1}{100}\right)^{0.286}(11.00)^{0.225}(4)$$

$$OM = \$6,100\ \text{yr}$$

To calculate total production costs in cents per thousand gallons, add the annual capital costs and annual O&M costs and divide by the yearly flow in thousands of gallons:

$$\text{Total Production Costs} = \left[(\$29,100 + \$6,100) \times \frac{100\ \text{cents}}{\text{dollar}}\right]$$

$$\div\ (365\ \text{days/yr}\ 11.680 \times 10^{3}\ \text{thousand gallons per day})$$

$$= 0.82\ \text{cents/1,000 gallons.}$$

B.3 DIFFUSED AERATION EXAMPLE COST CALCULATION

The following is an example calculation illustrating the methodology used to determine total capital costs and O&M costs to remove VOCs from drinking water by diffused aeration. Assume a plant flow of 952,000 gpd. The general assumptions listed in Section 7.2.2 are used in the example calculation, which is presented below.

O&M Costs

O&M costs are subdivided into energy, labor, and maintenance materials.

Energy--Determine system air requirements based on air-to-water ratio of 8 to 1.

$$(0.952 \text{ MGD})\ (694.4 \text{ gpm/MGD})\ (1 \text{ gal}/7.48 \text{ ft}^3)\ 8\ \frac{\text{air}}{\text{water}} = 706 \text{ cfm}$$

The horsepower requirements are calculated:

$$\text{Power (hp)} = \frac{0.227\ Q}{\%\ \text{efficiency} \times 100}\left[\left(\frac{P_1}{P_2}\right)^{0.283} - 1\right] \quad \text{(Fair, 1968)}$$

where: Q = air flow (cfm);

P_1 = operating pressure (psi), assumed to be 7 psi; and

P_2 = atmospheric pressure (psi) = 14.7 psi.

An efficiency of 70 percent is assumed. A general form of the equation is used to determine horsepower requirements per 1,000 cfm:

$$\text{hp}/1{,}000 \text{ cfm} = \frac{0.227\ (1{,}000)}{0.7}\left[\left(\frac{7 + 14.7}{14.7}\right)^{0.283} - 1\right] = 37.8 \approx 40$$

40 hp/1,000 cfm is used for all calculations.

For this case,

$$(40\ \text{hp}/1{,}000\ \text{cfm})\ 706\ \text{cfm} = 28.24\ \text{hp (use 30 hp)}$$

$$\text{Energy Costs (\$/yr)} = (\text{hp})\ (0.746\ \frac{\text{kw}}{\text{hp}})\ (24\ \frac{\text{hr}}{\text{day}})\ (365\ \frac{\text{day}}{\text{yr}})\ \frac{\$0.07}{\text{kw}}$$

$$= (30)\ (0.746)\ (24)\ (365)\ (0.07) = \$13{,}700/\text{yr} = 13.7\text{K\$/yr}$$

Labor and Maintenance Materials--The component quality method (Dorsey, 1982) is used to estimate labor and maintenance materials costs:

$$CQ = A\ (USRT)^a$$

where: a and A are empirical constants, and USRT is in ft^3 of aeration basin volume.

Based on a 20-minute detention time, basin volume is calculated to be:

$$\frac{(0.952\ \text{MGD})\ (694.4\ \text{gpm/MGD})\ (20\ \text{min})}{7.48\ \text{gal/ft}^3} = 1{,}767 \cong 1{,}770\ \text{ft}^3$$

Then, labor costs are estimated by the CQ method:

$$CQ\ (\text{hr/yr}) = 1.61\ (1{,}770)^{0.774} = 525.7$$

Use the labor rates in Table 7-1 to determine annual labor cost:

$$\$11/\text{hr} \times 525.7\ \text{hr/yr} = \$5{,}783/\text{yr}$$

Maintenance materials costs are estimated similarly:

$$CQ\ (\$/\text{yr}) = 48.33\ (1{,}770)^{0.4917} = \$1{,}912/\text{yr}$$

Total O&M:

Total O&M = Labor + Energy + Maintenance Materials
= 5,783 + 13,700 + 1,912
= $21,395/yr

Diffused aeration O&M costs are summarized in Table B.3-1.

Table B.3-1. Diffused Aeration--Operation & Maintenance Costs

Population/ Ave.Daily Flow,MGD	GPM	Aeration Basin (cu.ft.)	Labor ($K/yr)	Maintenance & Materials ($K/yr)	Energy ($K/yr)	Total ($K/yr)
25-100 .013	9	24	0.09	0.23	0.23	0.55
101-500 0.037	26	69	0.19	0.39	0.70	1.28
501-1000 0.093	65	173	0.40	0.61	1.83	2.83
1001-3300 0.280	194	520	2.24	1.05	4.58	7.87
3301-10000 0.952	660	1,770	5.78	1.91	13.70	21.39
10001-25000 2.753	1,912	5,112	13.14	3.22	38.90	55.26
25001-50000 6.065	4,212	11,260	24.22	4.75	82.34	111.30
50001-75000 11.680	8,110	21,690	40.22	6.55	159.00	205.78
75001-100000 15.912	11,050	29,540	51.09	7.63	217.00	275.71
100001-500000 36.806	25,560	68,340	97.78	11.52	500.00	609.30
500001-1000000 129.421	89,870	240,290	258.77	21.38	1,760.00	2,040.14
>1000000 517.491	359,350	960,820	756.46	42.26	7,026.00	7,824.71

MGD=Million Gallons Per Day
GPM=Gallons Per Minute

Capital Costs

Blower--Costs were obtained from another EPA contractor for air requirements less than 1,000 cfm and from manufacturers and distributors for blowers greater than 1,000 cfm. For 0.952 MGD, 706 cfm are required, the blower cost, from Table B.3-2; is $8,500 = 8.5$K.

Diffusers--

15 cfm/diffuser is assumed.

706 cfm/15 cfm/diffuser = 47 diffusers.

The unit cost for 47 diffusers is assumed to be $51 (Culp/Wesner/Culp, 1983).

$51/diffuser x 47 diffusers = $2,397 ≅ $2,400 = 2.4$K.

Piping--Assume piping costs are 20 percent of diffuser cost

(0.2) (2,400) = $480 = 0.48$K.

Installation--Assume installation costs are 50 percent of the sum of blower, diffuser, and piping costs:

0.5 (8,500 + 2,400 + 480) = $5,690 = 5.69$K

Contractor Overhead and Profit, Engineering Fees and Contingencies--

Assume 43.8 percent of total construction costs

(0.438) (Blower + Diffuser + Piping + Installation)

(0.438) (8,500 + 2,400 + 480 + 5,690) = 7,476 ≅ $7,480

Total Capital Costs--

Total Capital Costs = (Blower + Diffuser + Piping + Labor + Contingency, etc.) = 24,550 = 24.55$K

Annual Cost of Capital Expenditures--

Amortization at 12 percent for N = 20 years

$/yr = 24,550 x capital recovery factor

= 24,550 x 0.13388

= 3,286.75 ≅ $3,290/yr = 3.29$K/yr

Table B.3-2. Diffused Aeration--Construction Costs

Population/ Ave.Daily Flow,MGD	CFM	Blower ($K)	Diffuser ($K)	Piping ($K)	Labor ($K)	Subtotal ($K)	Total ($K)	Annual* ($K/yr)
25-100 0.013	10	0.40	0.10	0.02	0.26	0.78	1.12	0.15
101-500 0.037	28	0.60	0.20	0.04	0.42	1.26	1.81	0.24
501-1000 0.093	69	0.85	0.40	0.08	0.67	2.00	2.87	0.38
1001-3300 0.280	207	2.50	1.00	0.20	1.85	5.55	7.98	1.07
3301-10000 0.952	706	8.50	2.40	0.48	5.69	17.07	24.55	3.29
10001-25000 2.753	2,043	20.00	6.80	1.36	14.08	42.24	60.74	8.13
25001-50000 6.065	4,502	36.00	13.50	2.70	26.10	78.30	112.60	15.07
50001-75000 11.680	8,669	61.00	27.00	5.40	46.70	140.40	201.46	26.97
75001-100000 15.912	11,810	81.00	35.50	7.10	61.80	185.40	266.61	35.69
100001-500000 36.806	27,300	177.50	73.00	14.60	132.55	397.65	571.82	76.56
500001-1000000 129.421	96,100	529.00	256.00	51.20	418.10	1,254.30	1,803.68	241.48
>1000000 517.491	383,700	1,918.50	800.00	160.00	1,439.25	4,317.75	6,208.92	831.25

MGD=Million Gallons Per Day
CFM=Cubic Feet Per Minute
* Amortized at 12% , 20 yrs.

Cost ¢/1,000 Gal--

$$\frac{(\text{O\&M Cost} + \text{Annual Cost})\ 100}{\text{Flow } (1{,}000 \text{ gpd})\ 365}$$

$$\frac{(3{,}290 + 21{,}395)\ 100}{(952)\ (365)} = 7.1¢/1{,}000 \text{ gal}$$

Construction costs are summarized in Table B.3-2.

B.4 POWDERED ACTIVATED CARBON EXAMPLE COST CALCULATION

Cost assumptions listed in Section 7.2.3 are used in calculating estimated costs for removal of VOCs in drinking water by PAC. No capital costs are incurred since it is assumed that existing PAC feed facilities are adequate for VOC removal.

Estimated O&M costs are calculated for the 952,000 gpd (0.952 MGD) system size:

$$\$\text{K/yr} = \text{PAC dosage (mg/L)} \times 8.34\ \text{lb/MG/mg/L} \times \$\text{/lb PAC}$$

$$\times\ 365\ \text{days/yr} \times \frac{\text{Flow (MGD)}}{1{,}000}$$

$$= (20)\ (8.34)\ (0.43)\ (365)\ (0.952)/1{,}000 = 24.9\$\text{K/yr}$$

$$\text{¢}/1{,}000\ \text{gal} = (\$\text{K/yr})\ \left(\frac{\$1{,}000}{\$\text{K}}\right)\ \left(\frac{100\text{¢}}{\$}\right)\ \frac{1\ \text{yr}}{365\ \text{days}}\ \ \frac{1\ \text{day}}{\frac{\text{Flow (gpd)}}{1{,}000}}$$

$$= (24.9)\ (1{,}000)\ (100)/(365 \times 952) = 7.17 \cong 7.2\text{¢}/1{,}000\ \text{gal}$$

B.5 WELL FIELD MANAGEMENT EXAMPLE COST CALCULATION

Estimated costs were calculated using the assumptions listed in Section 7.2 for the non-treatment alternative of well field management for control of VOCs in drinking water. Estimated costs for O&M and construction are calculated in the following example and presented in Table B.5-1.

O&M Estimated Costs

O&M costs for well field management are limited to the cost of pumping. The friction head (h_f) is the only unknown variable that is needed for the calculation for the cost of energy for pumping:

$$h_f \text{ (ft)} = [Q(\text{MGD}) \,.\, (0.279 \times C \times D \text{ (ft)}^{2.63})]^{1.85} \times L \text{ (ft)}$$

(Clark, Viessman, and Hammer, 1979)

Assume a system size of 952,000 gpd or 0.952 MGD and 20 percent of the flow is to be pumped to waste:

$Q = (0.2)\ (0.952)$

$= 0.190$ MGD $= 0.294$ cfs $= 131.9$ gpm

$C = 130$ CIP, cement lined, good condition

$$A = \frac{Q}{V},\ A = \frac{D^2 \pi}{4} = \frac{Q}{V},\ D = \left(\frac{4\ Q}{\pi\ V}\right)^{1/2}$$

$$D\ 2\ \left(\frac{Q}{\pi}\right)^{1/2} \text{ since } V = 4 \text{ fps} = \left(\frac{0.294}{3.14}\right)^{1/2}$$

$$= 0.306 \text{ ft} \times 12 \frac{\text{in}}{\text{ft}} = 3.67 \text{ in; use 4-inch CIP}$$

$$L = 2{,}000\ D = 667 \text{ ft}$$

$$\text{then } h_f = [(0.190)/(0.279 \times 130 \times 0.333^{2.63})]^{1.85}\ (667)$$

$$= 8.44 \text{ ft}$$

Table B.5-1

Wellfield Calculations

Ave.Daily Flow,MGD	Q2(20%) MGD	D,in	D,rnd up	L,ft	HF friction	Energy Kwh/yr	O&M K$/yr	Pipe Cost $/ft	Cap Cost K$
0.013	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
0.037	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
0.093	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
0.280	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
0.952	0.190	3.67	4	667	8.4	24,050	1.68	10.91	10.46
2.753	0.551	6.25	8	1,333	4.1	66,160	4.63	16.58	31.79
6.065	1.213	9.27	10	1,667	7.5	151,603	10.61	20.45	49.01
11.680	2.336	12.87	14	2,333	6.9	289,836	20.29	27.39	91.90
15.912	3.182	15.02	16	2,667	7.2	396,639	27.76	35.94	137.82
36.806	7.361	22.85	24	4,000	7.1	916,225	64.14	64.90	373.30
129.421	25.884	42.84	48	8,000	5.0	3,143,069	220.01	173.69	1,998.13
517.491	103.498	85.67	96	16,000	4.5	12,486,386	874.05	347.38	7,992.52

D,rnd up= avail. pipe size

Q2= 20% of Q,MGD

K$= Costs in thousands

$$\text{Pumping Energy (hp)} = \frac{Q\ (\text{gpm}) \times \text{TDH (ft)}}{(3{,}960)\ (\text{efficiency})}$$

TDH = total dynamic head (ft)

= suction lift + static head + friction head

= 80 + 8.44

= 88.44 (ft)

Efficiency = 80% = 0.8

$$\text{hp} = \frac{(131.9)\ (88.44)}{(3{,}960)\ (0.8)}$$

$$= 3.68$$

$$\$/\text{yr} = 3.68\ \text{hp} \times 0.746\ \frac{\text{kw}}{\text{hp}} \times 24\ \frac{\text{hr}}{\text{day}} \times 365\ \frac{\text{day}}{\text{yr}} \times \$0.07/\text{kw hr}$$

= $1,685/yr

Capital Costs

The 1983 Dodge Guide was used to estimate costs for construction of the pipeline. All pipe is cement-lined cast iron pipe (CIP). Costs include excavation, pipe laying, thrust blocking, and backfilling. For a 4-inch pipe, the unit cost is $10.91/ft.

Construction costs = $10.91/ft x 667 ft = $7,277

Contractor overhead, profit, engineering, and contingencies:

43.8 percent of construction costs

Construction cost x 1.438 = Capital Cost

7,277 x 1.438 = $10,464 = 10.46 $K/yr

Annual cost amortized at 12 percent for 20 years:

Capital cost x capital recovery factor = annual cost

10,464 x 0.13388 = $1,401/yr = 1.4 $K/yr

$$\text{Cost ¢/1,000 gal} = \frac{(\text{Annual Cost} + \text{O\&M Cost})\ 100}{\frac{\text{Flow (gpd)}}{1{,}000}\ (365)}$$

$$= \frac{(1{,}401 + 1{,}685)\ 100}{(952)\ (365)}$$

$$= 0.89\text{¢/1,000 gal}$$

B.6 REGIONALIZATION EXAMPLE COST CALCULATION

The estimated cost of the non-treatment alternative for control of VOCs in drinking water by regionalization is based on the assumptions listed in Section 7.2.5. An example calculation is provided below for a system size of 952,000 gpd and a distance of 7.5 miles.

O&M Costs

O&M costs are divided into energy, labor, and maintenance materials costs.

Energy--The same procedures presented in Section B.5, Well Field Management, are used for regionalization:

$$h_f = L \times [O/(0.279 \times C \times D^{2.63})]^{1.85}$$

For $Q = 0.952$ MGD, $D = 12$ in, $C = 130$

$L = 7.5 \text{ mi} \times 5{,}280 = 39{,}600 \text{ ft}$

$h_f = 40$ ft

Static head = 80 ft

TDH = static + friction = 80 + 40 = 120 ft

$$\text{Energy cost (\$/yr)} = \frac{(Q)\ (TDH)}{(3{,}960)\ (0.8)}\ (0.746)(24)(365)(0.07)$$

$$= \$11{,}455/\text{yr}$$

Labor--Use component quality (CQ) method from "Drinking Water Cost Equation" (Dorsey, 1982):

$$CQ\ (\text{hr/yr}) = A\ (USRT)^r\ X^{TDH}$$

where: $A = 90.2$,

$USRT$ = flow (MGD),

$r = 0.755$, and

$X = 1$.

The labor rates shown in Table 7-1 are used to calculate annual labor costs.

$$\text{Labor cost } (\$/\text{yr}) = 11 \times CQ = 11 \times A(USRT)^{r}$$
$$= 11\ (90.2)\ (0.952)^{0.755}$$
$$= \$956/\text{yr}$$

Maintenance Materials--The same method (CQ) is used where A = 200.6:

$$CQ = A(USRT)^{r}\ X^{TDH}$$
$$CQ = 200.6\ (0.952)^{0.916}$$
$$= \$191/\text{yr}\ (1978)$$

where: USRT = flow (MGD),
r = 0.916,
X = 1, and
CQ = $/yr.

To convert to August 1983 dollars, the Producer Price Index (PPI) is used:

PPI August 1983 = 286.2
PPI 1978 = 199.7

$$\begin{array}{l}\text{Maintenance}\\ \text{materials}\end{array} (\$/\text{yr}) = CQ\ \frac{\text{PPI, Aug. '83}}{\text{PPI, 1978}} = 191\ \frac{286}{199} = \$275/\text{yr}$$

$$\text{Total O\&M} = \text{Energy} + \text{Labor} + \text{Maintenance Materials}$$
$$= 11{,}455 + 956 + 275$$
$$= \$12{,}686/\text{yr}$$
$$= 12.7\$K/\text{yr}$$

O&M costs are presented in Table B.6-1.

Capital Costs

Construction costs are due to pipeline, pump, and land costs.

Table B.6-1

Regionalization Costs
(Pipeline=7.5 & 10.5 miles)

Ave.Daily Flow,MGD	D,in	L,miles	Head Loss,ft			O&M Costs,K$/yr			TOTAL O&M	Capital Costs Pipe	Cost	Land	Pumping	Subtl	Total
			friction	static	TDH	Energy	Maint.	Labor	K$/yr	$/lin.ft	K$	K$	K$	K$	K$
0.013	3	7.5	23	80	103	0.134	0.005	0.015	0.155	7.21	285.5	11.4	6.5	303.4	436.3
0.037	4	7.5	22	80	102	0.378	0.014	0.034	0.427	10.91	432.0	11.4	10.6	454.0	652.9
0.093	6	7.5	16	80	96	0.895	0.033	0.068	0.996	14.29	565.9	11.4	16.1	593.3	853.2
0.280	8	7.5	30	80	110	3.088	0.090	0.379	3.557	16.58	656.6	11.4	28.1	696.1	1,001.0
0.952	12	7.5	40	80	120	11.455	0.275	0.956	12.686	23.50	930.6	11.4	51.5	993.5	1,428.7
0.013	3	10.5	32	80	112	0.146	0.005	0.015	0.167	7.21	380.7	11.4	6.7	398.8	573.4
0.037	4	10.5	31	80	111	0.412	0.014	0.034	0.460	10.91	576.0	11.4	10.9	598.3	860.4
0.093	6	10.5	23	80	103	0.956	0.033	0.068	1.057	14.29	754.5	11.4	16.4	782.3	1,124.9
0.280	8	10.5	43	80	123	3.453	0.090	0.379	3.922	16.58	875.4	11.4	29.2	916.1	1,317.3
0.952	12	10.5	57	80	137	13.078	0.275	0.956	14.308	23.50	1,240.8	11.4	54.2	1,306.4	1,878.6

K$= Costs in thousands

Pipeline Costs--The 1983 Dodge Guide was used for estimating the costs of pipeline construction. A 12-inch cement-lined CIP was used for this system size (0.952 MGD). The unit cost for the pipe is \$23.50/ft, including excavation, backfill, and thrustblocks.

$$\begin{aligned} \text{Pipeline cost (\$)} &= \text{(L) (Unit Cost)} \\ &= \text{(7.5 mi) (5,280 ft/mi) \$23.50} \\ &= \text{\$930,600} \end{aligned}$$

Land Cost--A 25-foot easement is necessary along the entire length of pipeline at \$500/acre.

$$\frac{\text{25 ft x (7.5 mi) (5,280 ft/mi)}}{\text{43,560 ft}^2\text{/acre}} \times \text{\$500/acre} = \text{\$11,364}$$

Pump Costs--From "Drinking Water Cost Equation" (Dorsey, 1982).

$$CC = K_2 \; USRT^{1} \; CCI^{m} \; O^{TDH}$$

where: CC = construction cost (\$/yr) at 8 percent for N = 20 years,

K^2 = 982.99,

USRT = flow (MGD) = 0.952,

1 = 0.4705,

$CCI = \frac{\text{Construction Cost Index}}{100} = 3.86$,

m = 0.993,

O = 1.002813, and

TDH = 120 ft (from same value calculated from Section B.6)

Then,

$$\begin{aligned} CC &= 982.99 \, (0.952)^{0.4705} \, (3.86)^{0.993} \, (1.002813)^{120} \\ &= \text{\$5,145/yr} \end{aligned}$$

Convert to present worth:

5,145 x present worth factor (i = 8 percent, N = 20)

5,145 x 9.818

= \$50,512

$$\begin{aligned}\text{Total capital} &= \text{total construction} \times 1.438\\ &= (\text{pipeline} + \text{land} + \text{pump})\ 1.438\\ &= (930{,}600 + 11{,}364 + 50{,}512)\ (1.438)\\ &= \$1{,}427{,}180\end{aligned}$$

$$\begin{aligned}\text{Annual cost} &= \text{total capital} \times \text{capital recovery facator}\\ &\quad (i = 12 \text{ percent, } N = 20)\\ &= 1{,}427{,}180 \times 0.13388\\ &= \$191{,}071/\text{yr}\end{aligned}$$

$$¢/1{,}000 \text{ gal} = \frac{(\text{O\&M} + \text{Annual Cost})\ 100}{(952)\ (365)} = 58.6\ ¢/1{,}000 \text{ gal}$$

Construction costs are presented in Table B.6-1 along with O&M costs.

B.7 BOTTLED WATER EXAMPLE COST CALCULATION

Cost estimates for the non-treatment alternative for VOC control by bottled water are based on the assumptions presented in Section 7.2.6. An example calculation for a system size of 952,000 gpd follows. Figure 7-1, obtained from "Technologies and Costs for the Removal of Fluoride from Potable Water Supplies" (EPA, 1984) was used to determine costs for the appropriate system size.

Capital costs, given in $K/yr, were converted to $K by applying the appropriate present worth factor for an interest rate of 12 percent and period of 20 years. These costs ($K) were then updated from mid-1982 dollars to August 1983 dollars by use of the appropriate ENR CCI.

For a system size of 0.952 MGD, read from Figure 7-1 a capital cost of 8 $K/yr. Apply the appropriate present worth factor:

$$8 \text{ \$K/yr} \times 7.469 = 60 \text{ \$K}$$

Applying the ENR CCI factor:

Mid 1982 = 356
August 1983 = 385

$$60 \text{ \$K} \times \frac{385}{356} = 65 \text{ \$K}$$

O&M costs were obtained from Figure 7-1 directly, which shows O&M costs for the given system size (0.952 MGD) to be about 300 $K/yr.

$$\text{Total annual cost} = \text{capital cost (\$K/yr)} + \text{O\&M costs (\$K/yr)}$$
$$= 8 + 300 = \$308 \text{ \$K/yr}$$

Apply the appropriate system size to obtain ¢/1,000 gal:

$$\frac{308 \text{ \$K/yr} \times 1{,}000 \text{ \$/K} \times 100 \text{ ¢/\$}}{952 \text{ (K-gal/day) } 365 \text{ days/yr}} = 88\text{¢}/1{,}000 \text{ gal}$$

B.8 ALTERNATE SOURCE EXAMPLE COST CALCULATIONS

Costs were estimated for non-treatment alternatives for the control of VOCs in drinking water by choosing an alternate source for all or a portion of a community's supply. The assumptions presented in Section 7.2.7 are used for the example calculation below. A system size of 952,000 gpd is used in the example.

O&M Costs

O&M costs are divided into energy, labor, and maintenance materials.

Energy--Friction head in the pipeline is calculated as shown in Sections B.4 and B.5. Table 7-58 which lists the assumptions used to estimate Alternate Source Costs shows a distance of 2.5 miles for the 0.952 MGD system size.

The friction head is calculated to be:

$$H_f = 1\ [Q/(0.279 \times C \times D^{2.63})]$$

$$= (2.5)\ (5{,}280)\ [0.952/(0.279 \times 140 \times (\tfrac{10}{12})^{2.63}\ ]^{1.85}$$

$$= 33.2 \text{ ft}$$

Static head = static + drawdown

Static lift = 80 ft + 30 ft = 110 ft

$$\text{Drawdown} = \frac{\text{Capacity of well (gpm)}}{\text{Specific capacity (25 gpm/ft)}}$$

From Table 7-58, the capacity of the wells for the 0.952 MGD system size is 220 gpm.

Static head = 110 + 220/25
= 118.8 ft

TDH = static + friction
= 118.8 + 33.2
= 152 ft

For existing surface supplies which must choose ground water supplies as an alternate source, TDH is used for the energy cost calculation. For existing ground water supplies, only the friction head (h_f) is used for energy cost calculation.

Existing surface water supply:

$$\text{Energy (\$/yr)} = \frac{Q\ (\text{gpm})\ (\text{TDH})}{(3{,}960)\ (0.8)}\ (0.746)\ (24)\ (365)\ (0.07)$$

$$\times\ (\text{No. wells in operation})$$

$$= (220)\ (152)\ (0.144)\ (3)$$

$$= \$14{,}486/\text{yr}$$

Existing ground water supply:

$$\$/\text{year} = (Q)\ (h_f)\ (0.144)\ (3) = 3{,}155$$

Labor--Component Quality (CQ) method is used:

$$CQ = A\ (USRT)^r$$

where:
CQ = hr/yr,
A = 140,
$USRT$ = flow (MGD),
r = 0.649, and
Labor rate = \$11/hr.

$$\$/\text{yr} = 11 \times CQ = (11)\ (140)\ (0.952)^{0.649}$$

$$= \$1{,}492/\text{year}$$

Maintenance Materials--Component Quality (CQ) method is used:

$$CQ = A(USRT)^r$$

where:
CQ = \$/yr,
A = 189.3,
r = 0.938, and
$USRT$ = flow (MGD).

= 189.3 (0.952)

= \$181/yr (1978)

Update to August 1983 by use of PPI:

$$(181)\ \frac{286}{1{,}997} = \$259/\text{yr}$$

Total O&M (existing surface supply)

= 14,486 + 1,492 + 259

= \$16,237/yr

Total O&M (existing ground water supplies)

= 3,155 + 1,492 + 259

= \$4,906/yr

O&M costs are presented in Table B.8-1.

Capital Cost

Transmission Line Cost--The cost of the transmission line was estimated by use of the 1983 Dodge Guide. A 10-inch, cement-lined CIP is listed as \$20.45 per ft, including excavation, backfilling, and thrust blocks.

$$\begin{aligned}\text{Transmission line cost (\$)} &= (\$20.45/\text{ft})\ (2.5\ \text{mi})\ (5{,}280\ \text{ft/mi}) \\ &= \$269{,}940\end{aligned}$$

Land acquisition for 25-ft easement for transmission line @ \$500/acre:

$$\begin{aligned}\text{Land for Easement} &= \$500/\text{acre} \times \frac{25\ \text{ft}\ (2.5\ \text{mi} \times 5{,}280 + 3\ \text{wells} \times 1{,}000\ \text{ft})}{43{,}560\ \text{ft}^2/\text{acre}} \\ &= \$4{,}648\end{aligned}$$

Well Installation--Well installation costs obtained directly from drillers and manufacturers include costs for drilling, well development, pump, and land at \$1,000/acre. One-fourth acre per well is assumed. Refer to Table B.8-2 for item costs.

Table B.8-1. August 1983 Operation and Maintenance Costs—Alternate Source (Costs in Thousand of Dollars)

Cost Category	System Size (MGD)											
	0.013	0.037	0.093	0.280	0.951	2.753	6.065	11.680	15.912	36.806	129.421	517.491
Energy GW*	0.016	0.077	0.217	0.9	3.1	4.4	11.8	12.5	12.8	28.9	57.3	366.9
SW†	0.175	0.476	1.3	4.2	14.5	22.1	53.7	52.6	71.1	105.9	231.5	1,319.8
Maintenance Material**	0.004	0.012	0.029	0.1	0.3	0.4	0.8	0.7	1.0	1.0	2.9	10.8
Labor	0.038	0.075	0.136	0.7	1.5	2.5	3.2	3.1	3.8	4.5	7.8	19.6
TOTAL GW	0.06	0.16	0.38	1.7	4.9	7.3	15.8	16.3	17.6	34.4	68.0	397.3
SW	0.22	0.56	1.47	5.0	16.2	25.0	57.7	56.4	75.9	111.4	242.2	1,350.2

*GW = Ground water supplies.
†SW = Surface water supplies.
**Adjusted to August 1983 dollars using BLS PPI for finished goods.

Table B.8-2. Alternate Source--Well Drilling Cost Estimates ($/Well)

System Size (MGD)	Well Size Diameter (in)	Drilling Cost ($)	Pump Cost ($)	hp	Type	Land Costs ($)	Total ($)
0.013	4	6,400	1,200	1.5	Sub	250	7,850
0.037	4	6,400	1,200	1.5	Sub	500	8,100
0.093	6	7,900	2,000	5	Sub	500	10,400
0.280	8	20,000	2,000	5	Sub	750	22,750
0.952	10	34,600	2,700	15	Sub	1,000	38,300
2.753	12	34,800	12,900	25	Turbine	750	48,450
6.065	16	58,200	13,530	50	Turbine	1,000	72,730
11.680	16	58,200	13,530	50	Turbine	1,000	72,730
15.912	16	58,200	14,275	75	Turbine	1,000	73,475
36.806	16	58,200	14,275	75	Turbine	1,500	73,975
129.421	16	58,200	14,275	75	Turbine	3,000	75,475
517.491	24	64,800	19,422	200	Turbine	5,000	89,220

Well installation cost = $38,300/well

Convert from June 1984 to August 1983 dollars using the CCI:

$$38{,}300 \times \frac{385}{387} = \$38{,}100/\text{well}$$

Total well installation = $38,100 x 4 wells
= $152,400

Total capital = (transmission + land + well installation) 1.438
= (269,940 + 4,648 + 152,400) 1.438
= $614,000

Annual cost = total capital x capital recovery factor
= $614,000 x 0.13388
= $82,200/yr

$$\text{¢}/1{,}000 \text{ gal} = \frac{(\text{Annual Cost} + \text{O\&M Cost})\ 100}{(952)\ (365)}$$

$$= \frac{(82{,}200 + 16{,}237)\ 100}{(952)\ (365)}$$

= 28.3¢/1,000 gal (existing surface water)
= 25¢/1,000 gal (existing ground water)

Capital costs are presented in Table B.8-3.

Table B.8-3. Construction Cost Estimates—Alternate Source (Costs in Thousands of Dollars) (Revised Transmission Costs October 9, 1983)

Cost Item	System Size (MGD)											
	0.013	0.037	0.093	0.280	0.952	2.753	6.065	11.680	15.912	36.806	129.421	517.491
Transmission	15.3	42.6	86.4	150.9	269.9	372.2	655.9	749.6	1,360.4	1,360.4	3,296.8	12,839.2
Land Acquisition (Easement for Transmission)	0.8	1.8	2.6	3.6	4.6	5.1	6.2	6.9	8.7	8.7	13.8	16.1
Well Installation*	7.9	16.1	20.7	68.0	152.4	144.7	289.3	289.3	292.5	441.7	901.3	1,774.8
Subtotal	24.0	60.5	109.7	222.5	426.9	522.0	951.4	1,045.8	1,661.6	1,810.8	4,211.9	14,630.1
Contingency (15 percent)	3.6	9.1	16.5	33.4	64.0	78.3	142.7	156.9	249.2	271.6	631.8	2,194.5
Contractors Overhead and Profit (12 percent)	2.9	7.3	13.2	26.7	51.2	62.6	114.2	125.5	199.4	217.3	505.4	1,755.6
Engineering Fees (15 percent)	4.0	10.2	18.4	37.4	71.7	87.7	159.8	175.7	279.1	304.2	707.6	2,457.9
August 1983 Costs	34.5	87.0	157.8	320.0	613.8	750.6	1,368.1	1,503.9	2,389.3	2,603.9	6,056.7	21,037.9
Annual Cost (12%, 20 years)	4.6	11.6	21.1	42.8	82.2	100.5	183.2	201.3	319.9	348.6	810.9	2,816.6

*Adjusted to August 1983 dollars using ENR CCI for June 1984 = 387 (base 1967 = 100).